NHI Course 132012

Soils and Foundations Workshop

Instructor's Guide

April 2002

NHI COURSE 132012
SOILS AND FOUNDATIONS WORKSHOP
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PREFACE

The Soils and Foundations Workshop (NHI Course No. 132012) is a basic geotechnical course which will provide practical knowledge for both generalists and those planning to take more advanced geotechnical courses in the future. The workshop will be of most benefit to bridge and foundation engineers; particularly those involved in the design and construction aspects of highway projects. The course objective is to impart to the participants the necessary knowledge and skills to determine the minimum level of geotechnical effort needed on a highway project. The participants will develop knowledge and appreciation of foundation activities in all project phases.

The course content follows a project oriented approach whereby the actual foundation work for a bridge project is traced from preparation of the boring request, to laboratory work, through design computations to construction activities. The concepts presented in each lesson are concise and specifically directed at a particular operation in the foundation design process. Recommendations are presented on how to efficiently layout borings, how to minimize approach embankment settlement, how to design the most cost-effective pile foundation, and how to transmit design information properly to construction. Basic examples are included in several lessons for hands-on knowledge. Continuity between lessons is achieved by sequencing the information in the normal progression of a foundation design study. In each phase of the fictitious project the soil concepts are developed into specific foundation designs or recommendations for that segment of the workshop design problem.

All participants will be provided with a copy of the Reference Manual and Participant Workbook. This Participant Workbook includes copies of visual aids and student exercises that closely follows the presentations being made by the instructors. The student exercises are designed to promote the interaction in the classroom, and to illustrate the basic principles and analyses. Solutions to the exercises are included in the back of the workbook. The Reference Manual (NHI-00-045), which was based on the 2nd edition of the previous Workshop Manual (1993), is geared to the practicing engineer who routinely deals with soils and/or foundations but has little theoretical background in soil mechanics or foundation engineering.

This Instructor's Guide is developed to provide an annotated outline and instructor's notes of the course that can be used as a guide during the preparation and delivery of the course by FHWA approved qualified Instructors.

ACKNOWLEDGEMENTS

Permission by the FHWA to adapt the July 1993 Soils and Foundations Workshop Manual prepared by Richard Cheney and Ronald Chassie (FHWA) and existing visual aids is gratefully acknowledged. Provision by the FHWA of the electronic files and hard copy of exhibits and visual aids is also acknowledged. Furthermore the efforts of Jerry DiMaggio, Andy Muńoz, Ivan Marreo, Chris Dumas, and Peter Osborn of the FHWA are acknowledged for their thorough technical reviews and recommendations.

The author would also like to acknowledge the assistance of Jeremy Hung (Project Manager), Nellie Finnegan, Roger Gobin, and a number of professionals from Parsons Brinckerhoff Quade and Douglas, Inc., in the preparation of this revision of the manual. Many thanks to Theresa Kong and Stanley Thomas for overall compiling, Roger Gobin for overseeing the preparation and production, and Theresa Kong, Stanley Thomas and Sandor Aguilar for graphic preparation and word processing.

NOTICE

The information in this document has been funded wholly or in part by the U.S. Department of Transportation, Federal Highway Administration (FHWA), under Contract No. DTFH-61-97-D-00025. The document has been subjected to peer and administrative review by FHWA, and has been approved for publication as an FHWA document.

In this document, certain products have been identified by trade name and/or shown in exhibits. Other products, which are not identified in this document, may be equally viable to those identified. The mention of any trade name or use of an exhibit containing the product does not constitute an endorsement or recommendation for use by either the authors or FHWA.

1.0 INTRODUCTION

Through the Indefinite Quantity Contract No. DTFH-61-97-D00025, Parsons Brinckerhoff Quade & Douglas, Inc. (PB) was retained by NHI/FHWA to develop the curriculum materials and revise the existing NHI course 13212 “Soils and Foundations Workshop” per Task Order 99-T-25048. The purpose is to revise the existing 4-day course presentation to an interactive format so the learner is actively involved in the learning experience.

The Soils and Foundations Workshop is a basic geotechnical course which will provide practical knowledge for both generalists and those planning to take more advanced geotechnical courses in the future. The workshop will be of most benefit to bridge and foundation engineers; particularly those involved in the design and construction aspects of highway projects. The course objective is to impart to the participants the necessary knowledge and skills to determine the minimum level of geotechnical effort needed on a highway project. The participants will develop knowledge and appreciation of foundation activities in all project phases.

This Instructor’s Guide is developed based on the approved revised Preliminary Lesson Plans submitted to NHI/FHWA on August 20, 1999 and provides an annotated outline of the course that can be used as a guide during the preparation and delivery of the course by FHWA approved qualified Instructors.

2.0 COURSE ORGANIZATION

The course will be presented by FHWA-approved instructors using a Participant Workbook, a Reference Manual, and various visual aids such as slides, transparencies, computer projections, and similar tools. The course is designed to begin at 1:00 PM on Monday and end at noon on Friday. Presentations by representatives of the host agency are planned for Monday PM and Friday AM in addition to a laboratory exercise in the agency soils lab on Tuesday AM.

All participants will be provided with a copy of the Reference Manual and Participant Workbook. The Reference Manual, which was based on the 2nd edition of the previous Workshop Manual (1993), is geared to the practicing engineer who routinely deals with soils and/or foundations but has little theoretical background in soil mechanics or foundation engineering. The manual content follows a project oriented approach whereby the actual foundation work for a bridge project is traced from preparation of the boring request, to laboratory work, through design computations to construction activities. Recommendations are presented on how to efficiently layout borings, how to minimize approach embankment settlement, how to design the most cost-effective pile foundation, and how to transmit design information properly to construction. Reference Manual will be referred to from time to time during the course so that the participants can become familiar with its contents.

The Participant Workbook is intended to be a set of copies of visual aids and student exercises that closely follows the presentations being made by the instructors. The student exercises are designed to promote the interaction in the classroom, and to illustrate the basic principles and analyses.

The course is divided into ten (10) distinct lessons, as shown in the following table. The sequence of lessons follows the order of presentations in both the Reference Manual and the Participant Workbook. The times for each topic may be varied by the instructor based on special interest by the audience in certain topic areas.

Lesson No.	Title	TIME	DAY
1.	Topic 1 - Introduction to Soils and Foundations Workshop	10 min	One
	Topic 2 - General Overview of Geotechnical Input to Highway Projects	60 min	One
2.	Topic 1 – Site Investigation and Sampling Methods in Highway Engineering – Chapter 2 (w/ state presentation)	100 min	One
	Topic 2 – Layout of Subsurface Investigation for a Bridge Foundation - Chapter 2	25 min	Two
3.	Basic Soil Properties for Foundation Design-Chapter 3 (w/ Lab. Session)	200 min	Two
4.	Laboratory Testing for Foundation Design-Chapter 4	115 min	Two
5.	Topic 1 – Slope Stability – Chapter 5	165 min	Two & Three
	Topic 2 – Solutions to Slope Instability – Chapter 5	80 min	Three
6.	Topic 1 – Embankment Settlement – Chapter 6	135 min	Three
	Topic 2 – Treatment for Embankment Settlement – Chapter 6	30 min	Three
7.	Topic 1 – Spread Footing Design- Bearing Capacity – Chapter 7	85 min	Three
	Topic 2 – Spread Footing Design-Settlement – Chapter 7	75 min	Four
8.	Topic 1 – Deep Foundation Design – Load Capacity – Chapter 8	155 min	Four
	Topic 2 – Deep Foundation Design – Pile Groups – Chapter 8	60 min	Four
9.	Topic 1 – Construction Control Considerations – Instrumentation - Chapter 9	40 min	Four
	Topic 2 – Construction Control Considerations – Foundations – Chapter 9 (w/ Two Breaks)	120 min	Four & Five
	Topic 3 – Construction Control Considerations – Pile Load Testing – Chapter 9	45 min	Five
10.	Foundation Investigation Report-Chapter 10 (w/ state presentation)	65 min	Five
11.	Team Exercises, Course Summary, Review, and Critique	60 min	Five

3.0 RECOMMENDED CLASS SIZE

The maximum class size permitted by NHI is 30 people to achieve the learning objectives for this course. All students should be instructed to bring calculators that have the capability to perform logarithmic functions. The NHI will ship 30 copies of each of the Reference Manual and Participant Workbook to the local DOT training coordinator at the address shown on the Course Request Form (1530). **It is recommended that the local DOT training coordinator distribute these manuals and workbooks to the participants 1 week in advance of the course and that the participants be encouraged by the local DOT training coordinator to scan the documents prior to coming to class.** In the event that these documents cannot be distributed prior to the course, a copy of each manual and workbook should be placed at each participant seating position by the local DOT training coordinator prior to the beginning of the class. All participants should also be advised to bring calculators that can perform trigonometric calculations, extract roots of numbers and accomplish similar functions; a writing pad for performing calculations; and a pen or pencil. NHI will also provide a registration form, course evaluation forms, CEU application forms, and course certificates. If changes to the number of manuals and workbooks or to the shipping address are necessary, please notify the NHI Training Officer at least 30 days prior to the course.

4.0 VISUAL AIDS/ ROOM AND EQUIPMENT NEEDS (INSTRUCTIONAL METHODS)

The classroom should be a large conference room or a similar room with a flat floor with sufficient tables and chairs for about 30 participants and an adequate ceiling height to permit visual aids to be clearly seen from the back of the room. The tables and chairs should be arranged in a classroom style with a suitable center aisle to permit instructor access to the students as a high level of interaction will be used to convey the learning objectives. The tables on either side of the center aisle should be placed at an angle to the aisle such that the overall configuration is a gentle 'V' shape that opens toward the instructor. All students should face the front of the room. The screen should be aligned with the center aisle. The room should be in a quiet area and should have a lighting system that permits convenient dimming of the room lights by the instructor. The room should also be available for the entire period of the course.

Visual aid information will be delivered primarily through PowerPoint presentations, overhead transparencies, flip charts, and computers although a 35 mm slides may be used to supplement certain presentations.

The instructors will provide the primary computer and a video display device to project the PowerPoint images on the screen; however, the Host Agency is requested to provide backup computer and LCD projector in case of the instructors' equipment failure.

The Host Agency should furnish the following materials and equipment, which will be needed by the instructors for presenting the visual aids. This equipment should be placed in the room and checked out at least 1 hour prior to beginning the first session by the instructor with technical assistance from the Host Agency.

- One overhead projector on a table or cart with wheels. A spare projector and bulb should be available that can be activated within 5 minutes in case of equipment failure.
- One 35 mm slide projector, similar to a Kodak Carousel, with a zoom lens

and 2 eighty-slide trays. A long extension cord (at least 6 m (20 feet) minimum) or other electronic remote device is needed to permit the instructor to advance the 35 mm slides from the front of the room.

- Two power strips.
- One dedicated large table in the front of the room for the overhead projector and computer.
- One dedicated small table on which to place the slide projector or video display device.
- One large screen positioned at the front of the room, which extends to a height of at least 3 m (10 feet).
- Two flip charts with markers.
- **BACK-UP EQUIPMENT.** An IBM compatible computer (with Pentium processor preferred at a speed of 700 MHz or faster) with Windows98 or later version of MS operating system and MS PowerPoint 2000 software installed and a compatible LCD projector that supports at least XGA resolution (1,024 by 768) and projects color images should be available that can be activated in 5 minutes in the event of equipment failure. Please provide any special computer commands or instructions necessary to project the computer screen images.

5.0 HOST STATE PARTICIPATION

One of the objectives of this training is to present practical aspects of geotechnical engineering, which can be used immediately by the students in everyday work. To accomplish this, the students need to understand the specific procedures used by the host State. The attached workshop schedule contains presentation times for representatives from the host State to explain their procedures.

Presentations of 30-45 minutes are proposed for both the State's Geotechnical Engineering Group on (Monday p.m.) and the Structures Unit on (Friday am). Suggestions for the Monday presentation by the Geotechnical Engineering Group include discussing both administrative details (how the unit is organized, the in-house capabilities as relates to soils borings and soils laboratory) and technical details (the basic geology of the State and the typical process followed to produce subsurface information for a typical project). Suggestions for the Friday presentation by a member of the Structures Unit include explaining the interaction of the structures and geotechnical units, and the procedures used by the structures unit in relation to design and/or review of foundations, and coordination with the geotechnical unit on response to field requests from construction for technical assistance related to foundations. The instructor should call the local NHI coordinator if additional information is needed for these presentations.

The objective of the Tuesday Host State presentation session is to familiarize the students with basic soil types found in the State, the procedures for soil description, and the laboratory facilities of the transportation agency. The session begins with the NHI instructors presenting a short slide and overhead presentation to explain basic soil properties and the procedures to be followed in the laboratory demonstration. Then the students are moved to the State laboratory for hands-on exercises and a tour of lab facilities. For the laboratory portion on Tuesday morning, adequate amounts of various soil types should be provided by the host agency so that the visual description process can be demonstrated by the instructors and then performed by the students. About three gallons of each of the following types of native soils are suggested so that all students can participate in the exercise.

- Coarse sand and gravel
- Uniform sand
- Predominately silt
- Silty clay
- Fat clay
- Organic silt
- Peat or muck

These samples should be at natural moisture content except for a small portion of each which should be dry. A tour of the agency's soils laboratory is undertaken during the Tuesday morning session. Since the agency is most familiar with its laboratory, we normally ask for assistance of the state's personnel in this matter to demonstrate index tests and describe strength and consolidation tests. The instructors will ask for the name of the technical coordinator so arrangements for the laboratory session can be finalized.

6.0 TARGET AUDIENCE

The categories of personnel at the transportation agency who could benefit from this workshop include drillers, geotechnical, bridge design, highway design, construction, and maintenance personnel. The personnel who will benefit the most are the first-line supervisors involved in the design of highway structures and embankments. The greatest impact will be achieved by convincing structural, design, and construction engineers to use procedures from this course as a guide for routine geotechnical work. All attendees should be encouraged to attend the entire course, not just sections that are in their specialty. One of the major benefits of this course is to give engineers an appreciation of activities outside their specialties that influence, or are influenced by, the work of the geotechnical engineer. The one exception is for drillers, who could be invited to attend only the first day of the course (Monday PM and Tuesday AM).

6.1 Pre-Training Competencies

This course is geared to practicing engineers who routinely deal with soils and foundations problems. No theoretical background is required in soil mechanics or foundation engineering although computational skills are necessary for the design sessions. This course is the entry level in geotechnical engineering.

7.0 OVERALL COURSE LEARNING OBJECTIVES

The course objective is to impart to the participants the necessary knowledge and skills to determine the minimum level of geotechnical effort needed on a highway project. A high level of interaction between the expert instructor(s) and the students will be used to facilitate the development of knowledge and skills in basic geotechnical concepts and analyses. Upon completion of the course, the participants will have demonstrated learning of the following:

1. Knowledge of the minimum level of geotechnical input in various project phases of a highway project,

2. Knowledge of the equipment and procedures used to implement a subsurface investigation of soil and rock conditions,

3. Knowledge and basic skill in visual description of soils native to the host state,

4. Knowledge of the geotechnical laboratory facilities and personnel in the host state,

5. Knowledge of the basic soil test procedures and application of soil test results to highway projects,

6. Knowledge and basic skills in procedures used for both settlement and stability analysis, and knowledge of design solutions to stability and settlement problems,

7. Knowledge and basic skills in procedures used for determining bearing capacity and settlement of spread footing foundations,

8. Knowledge and basic skills in the design and construction management of driven pile foundations,

9. Knowledge of driven pile foundation construction equipment and construction inspection,

10. Knowledge of static load testing and basic skill to interpret static load test results, and

11. Knowledge of the format and minimum content of an adequate foundation report.

8.0 POTENTIAL INSTRUCTORS

Primary Instructor – Richard Cheney, Senior Supervising Geotechnical Engineer, Parsons Brinckerhoff Quade Douglas, Inc.
Second Instructor – John Walkinshaw, Senior Supervising Geotechnical Engineer,

Parsons Brinckerhoff Quade & Douglas, Inc.

The course is designed to be delivered by a primary instructor with extensive experience in applying geotechnical principles to design and construction of transportation facilities, and detailed knowledge of the geotechnical procedures and practices of both FHWA and the state DOT's. The course is also designed in a way that a qualified instructor from FHWA or the host state agency may serve as the second instructor.

9.0 COURSE AGENDA

DAY ONE P.M.

1:00 p.m.	Welcome Administrative Details	***State Representative***
1:15 p.m.	Lesson 1: Topic 1 Introduction to the Soils & Foundations Workshop	*1st Instructor*
	Lesson 1: Topic 2 General Overview of the Geotechnical Input to Highway Projects	*1st Instructor*
2:25 p.m.	BREAK	
2:40 p.m.	Lesson 2: Topic 1 Site Investigation Exploration and Sampling Methods	*2nd Instructor*
3:50 p.m.	MINI BREAK	
4:00 p.m.	Typical Foundation Exploration Program Done by Host Agency	***State Representative***
4:30 p.m.	CLOSING	

Wear work clothes to Tuesday a.m. lab sessions
<u> Hands-on student exercise problems begin Tuesday - bring calculators.</u>**

DAY TWO

8:00 a.m.	Lesson 2: Topic 2 How to Lay Out Subsurface Exploration Program for a Bridge Foundation	*1st Instructor*
8:25 a.m.	Lesson 3: Introduction to Soil Testing	*1st Instructor*
9:10 a.m.	Review Foundation Design Objectives A. Discuss Processing of Soil Samples in Lab B. Visual Soil Description System ("MUD")	*1st Instructor*
9:30 a.m.	BREAK	

GO TO DOT LABORATORY

9:45 am	Students Visual Soil Identification Exercise in DOT Lab.	***Instructors &***
& 10:45 a.m.	Lab Walk-Thru and Demonstration of Test Methods	***Host Lab Personnel***

RETURN TO MAIN CLASSROOM

11:30 a.m.	Lesson 3 (Cont'd.) Discussion of Lab Exercise ** GEOQUIZ	*1st Instructor*
12:00 p.m.	LUNCH	
1:00 p.m.	Lesson 4: Selection of Soil Design Parameters A. Effective Stress Principle B. Po Diagram * C. Po Diagram – Student Exercise	*1st Instructor*
2:00 p.m.	BREAK	
2:15 p.m.	Lesson 4 (cont'd): Lab Testing Program Developed D. Consolidation Tests for Settlement E. Strength Tests for Stability and Bearing Capacity F. Apple Freeway Design Problem	*1st Instructor*
3:10 p.m.	MINI BREAK	
3:15 p.m.	Lesson 5: Topic 1 Slope Stability A. Circular Arc Failure	*2nd Instructor*

**B. Student Mini-Exercise

4:30 p.m. CLOSING

DAY THREE

8:00 a.m. Lesson 5: Topic 1 (Cont'd) *2nd Instructor*
C. Sliding Block Failure
**D. Sliding Block - Student Exercise

Demonstrate Slope Stability Computer Program *1st Instructor*

9:15 am BREAK

9:30 am Lesson 5: Topic 2 Solutions to Slope Instability *2nd Instructor*
A. Design Solutions to Stability Problems
B. Cut Slope Stability
C. Lateral Squeeze
**D. Student Mini-Exercise- Stability Solutions
E. Apple Freeway Workshop Design Problem

10:50 a.m. MINI-BREAK

11:00 a.m. Lesson 6: Topic 1 Embankment Settlement *2nd Instructor*
A. Major Design Considerations Settlement Amount and Time
B. Embankment Pressure Distribution

12:00 p.m. LUNCH

1:00 p.m. *2nd Instructor*
C. Settlement Analysis - Granular Soils
**D. Student Mini-Exercise - SPT Correction and "C Value
E. Settlement Analysis - Cohesive Soils
**F. Student Exercise - Settlement and Time Estimate for Embankment Over Clay
Demonstration of EMBANK Program

2:15 p.m. BREAK

2:30 p.m. Lesson 6: Topic 2 Treatments for Embankment Settlement Problems *2nd Instructor*
A. Methods To Reduce Settlement Amount And/Or Time
B. Lateral Squeeze Settlement Analysis –

	Apple Freeway Workshop Design Problem	
3:00 p.m.	MINI-BREAK	
3:05 p.m.	Lesson 7: Topic 1 Spread Footing Design; Bearing Capacity A. Bearing Capacity of Spread Footings **B. Student Exercise - Bearing Capacity	*1st Instructor*
4:30 p.m.	CLOSING	

DAY FOUR

8:00 a.m.	Lesson 7: Topic 2 Spread Footing Design; Settlement A. Settlement of Spread Footings **B. Student Exercise - Footing Settlement Apple Freeway Workshop Design Problem C. Footing Bearing Capacity D. Footing Settlement	*1st Instructor*
9:15 a.m.	BREAK	
9:30 a.m.	Lesson 8: Topic 1 Deep Foundation Design - Load Capacity A. Granular Soils (Nordlund's Method)	*1st Instructor*
10:30 a.m.	MINI-BREAK	
10:40 a.m.	B. Cohesive Soils (Tomlinson's Method) **C. Student Exercise - Static Analysis	*1st Instructor*
12:00 p.m.	LUNCH	
1:00 p.m.	Demonstration of SPILE/DRIVEN Programs	*1st Instructor*
1:15 p.m.	Lesson 8: Topic 2 Deep Foundation Design -Pile Groups Workshop Problem - Pile Design	*1st Instructor*
2:15 p.m.	BREAK	

2:30 p.m.	Session 9: Topic 1 Construction Aspects–Instrumentation	*2nd Instructor*
3:10 p.m.	Mini-BREAK	
3: 15 p.m.	Session 9: Topic 2 Construction Aspects–Foundations A. Pile Driving Equipment B. Pile Driving Formula C. Dynamic Analysis/Wave Equation Introduction **D. Student Exercise – Pile Driveability	*1st Instructor*
4:30 p.m.	CLOSING	

DAY FIVE A.M.

8:00 a.m.	Session 9: Topic 2 Construction Aspects (Cont'd) **E. Student Exercise - Hammer Approval F. Apple Freeway Workshop Design Problem	*1st Instructor*
8:45 a.m.	Lesson 9: Topic 3 Construction Aspects -Pile Load Testing ** Student Exercise – Load Test Interpretation	*2nd Instructor*
9:30 a.m.	BREAK	
9:45 a.m.	DOT FOUNDATION REPORTS How field data are used. Alternates considered. Analysis methods used. Information presented in Foundation Report. Information presented in Plans and Specifications. Designer Utilization of Foundation Data.	***State Representative***
10:20 a.m.	MINI-BREAK	
10:30 a.m.	Lesson 10: Foundation Investigation Report A. Guidelines for Writing a Good Report B. What the Report Should Contain C. Use of Special Notes D. Information Made Available to Contractor E. Use of "Disclaimers"	*2nd Instructor*

	Workshop Design Problem – Foundation Investigation Report	
11:00 a.m.	Team Problem Session Group Discussion of Workshop Learning Objectives Complete Course Critique Forms	*ALL*

CLOSING

Lesson No: 1 (Topic 1)

Lesson Title: Introduction to Soils and Foundations Workshop

Performance Based Learning Objectives: Participants should be able to:

- Discern the difference between knowledge of geotechnical concepts and skills developed in geotechnical activities.

Instructional Method: Description of interactive teaching techniques. The lesson will begin with a display of overall learning objectives and the general sequence in which lessons will be taught. The group will be asked to comment on specific items in each lesson area, which they consider, of most interest. Ask group what they want to learn from this workshop, and list course objectives on a flip chart. After list is complete, tell students what will and will not be covered in course. Give recommendations for other courses where non-covered items are taught. Then the instructor introduces the concept that technical instruction seeks to produce one of two primary learning outcomes; knowledge and/or skill. Knowledge is the ability to intellectually understand a technical process and is learned by presentation or demonstration. Skill is the ability to perform the technical task and is learned by practice. Students will be asked to identify items from a list, which are either skills or knowledge. Instructor then notes that each lesson will begin with a statement of learning objectives and skills to be acquired.

Instruction Day: Day 1 – P.M.

Time Allocation: 10 minutes

Evaluation Plan: Group responds to questions to develop definition of skill versus knowledge to understand the need for the interactive approach.

Reference: *The First Time Trainer*; American Management Association, 1601 Broadway, NYC, NY. 10019; http://www.amanet.org

Lesson No: 1 (Topic 2)

Lesson Title: General Overview of Geotechnical Input to Highway Projects

Performance Based Learning Objectives: Participants should be able to:

- Recognize the general significance of basic geotechnical activities,
- Relate which geotechnical activities are performed in various project phases,
- Recall that testing, theory and experience are of equal importance in geotechnical engineering activities.

Instructional Method: This presentation will be used to establish that a practical approach will be used as well as to show group how case histories will be used to emphasize important learning objectives in the course. Use slides to show the names of each major geotechnical activity. Illustrate importance of geotechnical input in various project phases with single slide case histories. Review activities sequence in manual and ask students to highlight important areas.

Instruction Day: Day 1 – P.M.

Time Allocation: 60 minutes

Evaluation Plan: Question-answer session to determine students' pre-knowledge of geotechnical activities in various project phases before general description of each major phase. This pre-knowledge will provide the instructors an insight into the level of geotechnical knowledge of the students. Refer to objectives list after each session to reinforce what was learned in that session or to add to list if other objectives achieved which were not on original list.

Reference: None.

Lesson No:	2 (Topic 1)
Lesson Title:	Site Investigation and Sampling Methods
Performance Based Learning Objectives:	Participants should be able to: • Recognize basic site exploration and sampling methods, • Describe the SPT test.
Instructional Method:	Use slides of site exploration equipment and case histories common to host state geologic conditions to show importance of good site investigation techniques. Review manual contents and highlight important items such as SPT information, typical boring log format, and general highway exploration layout guidelines. Use overheads to show minimum guidelines. Use guest speaker to focus on state procedures, familiarize students with agency personnel, and describe state geology, agency site investigation equipment and techniques. Encourage students to ask agency specific questions to speaker.
Instruction Day:	Day 1 – P.M.
Time Allocation:	100 minutes
Evaluation Plan:	Question-answer periods on general knowledge of drilling equipment, why standard procedures needed, how to find SPT value, and why minimum site investigation guidelines needed. Follow up after Lesson 2-topic 2 completed with additional questions on topic 1 area to test learning.
Reference:	AASHTO Manual on *Subsurface Investigations*, 1988, Wash. DC 20001; http://www.aashto.org, telephone 1-202-624-5800 Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications; 1988, FHWA ED-88-053, http://www.fhwa.dot.gov/bridge/geotechnical

Lesson No:	2 (Topic 2)
Lesson Title:	Layout of Subsurface Investigation for a Bridge Foundation
Performance Based Learning Objectives:	The participant should be able to: • Explain the steps in the layout of a subsurface investigation for a bridge foundation as described in lesson 1, topic 1.
Instructional Method:	Use transparencies to emphasize the basic steps and the minimum extent of the subsurface program for a structure foundation. Review manual sections and ask students to highlight important areas of the guidelines. Introduce Apple Freeway serialized problem. Show how to layout the site investigation. Then show student exercise on overhead.
Instruction Day:	Day 2 – A.M.
Time Allocation:	25 minutes
Evaluation Plan:	Use group exercise to layout site exploration steps and fill in requirements for a site investigation plan on the Apple Freeway (1). Reinforce topic 1 area objectives (1) with questions on SPT and overall process of site exploration in the Apple Freeway including what shallow auger holes will be used for in design.
Reference:	*AASHTO Manual on Subsurface Investigations*, 1988, Wash. DC 20001; http://www.aashto.org, telephone 1-202-624-5800 *Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications*; 1988, FHWA ED-88-053, http://www.fhwa.dot.gov/bridge/geotechnical

Lesson No: 3

Lesson Title: Basic Soil Properties for Foundation Design

Performance Based Learning Objectives: The participants should be able to:

- List main soil group and basic engineering uses,
- Differentiate between identification, description and classification.

Instructional Method: Use slide presentation to show basic soil properties of main soil groups. Review soil description procedure in manual via overheads. Pre-quiz students on what lab tests they think are now done in the lab. Take students to soils lab and spilt into groups for visual description exercise. Introduce soils lab personnel and ask for lab tour and demonstration of basic equipment in lab. Return to classroom for group quiz on soil uses. Overview rock properties in manual and show how basic soil information used to develop soil profile. Demonstrate soil profile development for Apple Freeway.

Instruction Day: Day 2 –A.M.

Time Allocation: 200 minutes

Evaluation Plan: Student exercise on soil description involves each student visualizing about 8 soil samples and responding as a group on the engineering properties of each sample (1,2). Lab tour by agency lab staff promotes questions on equipment and procedures. Group quiz on basic soil types and properties (1). Ask what information was used to develop Apple Freeway soil profile.

Reference: *AASHTO Manual on Subsurface Investigations*, 1988, Wash. DC 20001; http://www.aashto.org, telephone 1-202-624-5800

Lesson No: 4

Lesson Title: Laboratory Testing for Foundation Design

Performance Based Learning Objectives: The participants should be able to:

- Compute and plot total stress, water pressure and effective stress on a Po diagram
- Define the purpose of both consolidation and strength testing for foundation design.

Instructional Method: Begin by showing pre-quiz of what tests student thought were available in lab and ask for additions based on lab visit. Use slide presentation to present concepts of effective stress, consolidation, and soil strength. Use demonstration and then skills exercise to learn effective and total stress computational method. Relate strength to stability and consolidation to settlement and long-term maintenance. Focus on what students saw in lab tour when discussing soil testing and results. Demonstrate how to apply concepts and results to actual problem in Apple Freeway project. IMPORTANT: Review with students the basic concepts in the soil properties and lab test sections. Remind students that this is the data-gathering phase that must occur before analysis.

Instruction Day: Day 2 –P.M.

Time Allocation: 115 minutes (does not include lab tour)

Evaluation Plan: Use skill exercise to evaluate learning of effective and total stress computational method (1). Use Apple Freeway to test application of effective stress concepts lab tests and to summarize of lab test results. (1,2). Show original flip chart objectives and ask which learning objectives were achieved.

Reference: *AASHTO Manual on Subsurface Investigation* 1988, Wash. DC 20001; http://www.aashto.org, telephone 1-202-624-5800

Lesson No: 5 (Topic 1)

Lesson Title: Slope Stability

Performance Based Learning Objectives: The participants should be able to:

- Explain the effect of water on frictional resistance
- Compute resisting and driving forces, and
- Analyze an embankment by the sliding block method.

Instructional Method: Use slides presentation and case histories of local geologic area to overview embankment stability. Go to manual and highlight the effects of water and need for safety factors. Highlight recommended safety factor and discuss values with class. Use overheads to show basic circular stability concept. Demonstrate with Apple Freeway project hand solution. Continue with sliding block stability concept and student exercise. Demonstrate XSTABL and show why computer solution is necessary.

Instruction Day: Day 2 P.M. / Day 3 A.M.

Time Allocation: 165 minutes

Evaluation Plan: Use student exercise on simple block analysis to develop skill and relate how various treatments improve safety factor. Ask individual tables if safety factors are acceptable, what solutions they chose and why (2, 4, 5). Before starting Apple Freeway, ask students what 3 types of failure must be considered (1). Demonstrate practical application in Apple Freeway and extend to surcharge effects by asking questions about effects of surcharge before showing solution (4). Show original flip chart objectives and ask which learning objectives were achieved.

Reference: Transportation Research Board Special Report No.247
*Landslide; Investigation and Mitigation,*1996.
http://www.nas.edu/trb

Lesson No:	5 (Topic 2)
Lesson Title:	Solutions to Slope Instability
Performance Based Learning Objectives:	The participant should be able to: • Discuss solutions to stability problems.
Instructional Method:	Overview the options for remediation stability problems by the use of schematics and case history slides. Ask what treatments have been used by the agency. Ask students to apply remedial methods to improve stability of embankment shown in earlier exercise in topic 1. Use Apple Freeway to test overall knowledge of stability concepts.
Instruction Day:	Day 3 AM
Time allocation:	80 minutes
Evaluation Plan:	Student exercise will be used to test student ability to select remedial treatments. Instructor will quiz students on practical aspects of building solutions in the field. After exercise the instructor will use the Apple Freeway to test overall student learning of stability concepts.
References:	None

Lesson No:	6 (Topic 1)
Lesson Title:	Embankment Settlement
Performance Based Learning Objectives:	The participant should be able to: • Estimate compressibility from basic soils data, • Calculate settlement.
Instructional Method:	Use slides presentation and case histories of local area to show settlement causes, and effects. Show basic procedures for settlement of embankments on both granular and cohesive soils. Use mini-exercises to develop settlement computation skills after showing concepts. Demonstrate FHWA computer program EMBANK to show how results are extended to more detailed solution with little effort.
Instruction Day:	Day 3 A.M. / P.M.
Time Allocation:	135 minutes
Evaluation Plan:	Use student exercise for SPT method in granular soils and relate to previous effective stress problem (1,2). Use student exercise for cohesive settlement problem and ask for both magnitude and time (2).
Reference:	NCHRP Synthesis 159*, Design/Construction of Bridge Approaches*, 1990; http://www.nas.edu/trb

Lesson No: 6 (Topic 2)

Lesson Title: Treatment for Embankment Settlement Problems

Performance Based Learning Objectives: The participant should be able to:

- Propose solutions to embankment settlement problems.

Instructional Method: Use slides presentation and case histories of local area to show remedial treatments. Pass around a section of a wick drain to impress students with simplicity of treatments. Ask what treatments agency has used and success or problems found. Use Apple Freeway to test knowledge of how to use treatment methods to reduce settlement. Relate methods used to costs of alternates in actual project.

Instruction Day: Day 3 –P.M.

Time Allocation: 30 minutes

Evaluation Plan: Ask students to identify which of the treatment methods can be effective to reduce settlement on the Apple Freeway. Show original flip chart objectives and ask which learning objectives were achieved.

Reference: NCHRP Synthesis 159*, Design/Construction of Bridge Approaches*, 1990; http://www.nas.edu/trb

Lesson No: 7 (Topic 1)

Lesson Title: Spread Footing Design- Bearing Capacity

Performance Based Learning Objectives: The participants should be able to:

- Explain how footing embedment, width and water table affect bearing capacity.

Instructional Method: Use a short slide presentation to show bearing capacity concepts. Emphasize basic concepts in case history. Explain computation process. Discuss factors influencing bearing capacity as part of group exercise. Ask students to do exercise on bearing capacity.

Instruction Day: Day 3 P.M.

Time Allocation: 85 minutes

Evaluation Plan: Use group exercise to provide awareness of major issues (embedment, width, water table) which impact bearing capacity. Use student exercise to develop skills in basic bearing capacity and settlement of spread footings. After exercise return to slide of failure and ask how did this occur?

Reference: NCHRP Synthesis 107; *Shallow Foundations for Highway Structures,* 1983; http://www.nas.edu/trb
FHWA RD86-185; *Shallow Foundations for Highway Structures*, 1987; http://www.fhwa.dot.gov/bridge/geotechnical

Lesson No: 7 (Topic 2)

Lesson Title: Spread Footing Design-Settlement

Performance Based Learning Objectives: The participants should be able to:

- Perform settlement analysis in both cohesive and granular soil,
- Name solutions to reduce settlement amount or time.

Instructional Method: Use short slide presentation to show settlement concepts for spread footing design. After slides, demonstrate settlement method and then ask students to do exercise. Ask students to interpret results. Show Apple Freeway solution and question students on both bearing capacity and settlement issues related to actual project.

Instruction Day: Day 4 A.M.

Time Allocation: 75 minutes

Evaluation Plan: Use student exercises to develop skills in settlement of spread footings (1). Ask students to interpret result from settlement problem (1). Quiz students during Apple Freeway solution on meaning of computational results (2). Show original flip chart objectives and ask which learning objectives were achieved.

Reference: NCHRP Synthesis 107; *Shallow Foundations for Highway Structures,* 1983; http://www.nas.edu/trb
FHWA RD86-185; *Shallow Foundations for Highway Structures*, 1987; http://www.fhwa.dot.gov/bridge/geotechnical

Lesson No: 8 (Topic 1)

Lesson Title: Deep Foundation Design – Load Capacity

Performance Based Learning Objectives: The participants should be able to:

- Describe the properties of the pile and the ground which affect bearing capacity.

Instructional Method: Use detailed slide presentation to show deep foundation types and basic concepts (including example problem) for the design of single driven piles. Demonstrate the analysis procedure for both granular soil and cohesive soil. Present student exercise involving both granular and cohesive soil concepts. Demonstrate SPILE and DRIVEN computer programs and stress alternate pile type analysis. Use group exercise to compute pile capacities for simple profile. Relate Apple Freeway computations of alternates to pile selection by designer.

Instruction Day: Day 4 A.M. / P.M.

Time Allocation: 155 minutes

Evaluation Plan: Use student skill exercise on static pile capacity (1). Exercise relies on knowledge and skills previously learned about effective stress and the SPT method (reinforces sessions 2 and 3 with questions). After demonstration of SPILE and DRIVEN, ask questions about driving resistance related to project situations such as scour. Quiz students during Apple Freeway solution about meaning of results (1).

Reference: FHWA HI-97-013, *Design/Construction of Driven Pile Foundations*, 1997; http://fhwa.dot.gov/bridge/geotechnical

Lesson No:	8 (Topic 2)
Lesson Title:	Deep Foundation Design – Pile Groups
Performance Based Learning Objectives:	The participants should be able to: • Recognize the effect of pile spacing, settlement and negative skin friction.
Instructional Method:	Use slides presentation to overview group issues such as efficiency, pile settlement, and downdrag. Use Apple Freeway to quiz student on group issues for this practical problem.
Instruction Day:	Day 4 P.M.
Time Allocation:	60 minutes
Evaluation Plan:	Quiz students on potential group problems for the Apple Freeway project.
Reference:	FHWA HI-97-013, *Design/Construction of Driven Pile Foundations*, 1997; http://fhwa.dot.gov/bridge/geotechnical

Lesson No: 9 (Topic 1)

Lesson Title: Construction Monitoring and Quality Assurance - Instrumentation

Performance Based Learning Objectives: The participants should be able to:

- Recall the basic types of geotechnical instrumentation.

Instructional Method: Use a brief slide presentation to overview the use of geotechnical instrumentation on highway projects. Use Apple Freeway problem to test student knowledge of what instruments would be selected for a typical project.

Instruction Day: Day 4 P.M.

Time Allocation: 40 minutes

Evaluation Plan: Use the Apple Freeway as a mini-student exercise to test application of instrument knowledge to an actual project.

Reference: FHWA HI-97-013, *Design/Construction of Driven Pile Foundations*, 1997; http://fhwa.dot.gov/bridge/geotechnical

Lesson No: 9 (Topic 2)

Lesson Title: Construction Monitoring and Quality Assurance- Foundations

Performance Based Learning Objectives: The participants should be able to:

- Apply dynamic analysis to pile design,
- Evaluate pile equipment acceptability.

Instructional Method: Use slides to describe pile-driving equipment. Overview wave mechanics concepts and dynamic analysis. Use transparencies and highlight important items concerning dynamic formula in manual. It is optional for the instructor to use computer program GRLIMAGE to show wave mechanics and GRLWEAP to show wave equation features. Show how to interpret wave equation output and relate to hammer approval, design check of pile driveability and production pile driving criteria development. Use group student exercises to demonstrate concepts.

Instruction Day: Day 4 P.M. / DAY 5 A.M.

Time Allocation: 120 minutes

Evaluation Plan: Use group student exercises with wave equation results to select pile size and approve pile-driving equipment (1,2). Ask students what items are controlled in their pile specification (2).

Reference: FHWA HI-97-013, *Design/Construction of Driven Pile Foundations*, 1997; http://fhwa.dot.gov/bridge/geotechnical

Lesson No: 9 (Topic 3)

Lesson Title: Construction Monitoring and Quality Assurance- Pile Load Testing

Performance Based Learning Objectives: The participant should be able to:

- Relate pile construction control to design safety factor,
- Determine pile failure load.

Instructional Method: Present a slide presentation showing load testing on representative projects. Use overheads to overview load testing concepts in static and dynamic testing. Highlight procedure in an example for load test interpretation. Use student exercise to interpret load test curve for failure load. Discuss safety factor reductions if load testing used and ask students what safety factors they think should be used for various test methods. Relate load testing to cost savings; particularly on major projects.

Instruction Day: Day 5 A.M.

Time Allocation: 45 minutes

Evaluation Plan: Question students on agency policy on load testing and frequency of load tests on recent projects (1). Use student exercise to evaluate skill in load test interpretation (2). Use Apple Freeway to test student learning for the construction control lesson.

Reference: FHWA SA 91-042, *Static Testing of Deep Foundations*, 1992.
http://fhwa.dot.gov/bridge/geotechnical

Lesson No: 10

Lesson Title: The Foundation Investigation Report

Performance Based Learning Objectives: The participant should be able to:

- Recall the contents of a foundation report.

Instructional Method: Introduce the agency speaker from the foundation section who will explain the procedures used by the agency to develop a foundation report and respond to questions from the group/instructors. A recent typical project is commonly used to allow the students to relate to specific situations in the host state. After the presentation, the instructor uses overheads to review guidelines of what a foundation report should contain and what information should be placed in the contract documents. Ask students to read final report for Apple Freeway.

Instruction Day: Day 5 A.M.

Time Allocation: 35 minutes host agency
30 minutes instructor

Evaluation Plan: Group discussion of agency procedures for review and distribution of both in-house and consultant reports (1). Group discussion of information contained in a typical foundation report and of report distribution (1). Group discussions of final report (1).

Reference: *AASHTO Manual on Subsurface Investigations*, 1988, http://www.aashto.org, telephone 1-202-624-5800

Lesson No: 11

Lesson Title: Course Summary, Review, and Critique

Performance-Based Learning Objectives: Participants should be able to:

- Review the overall learning objectives
- Identify at least one new skill learned
- Apply new skill or knowledge to a particular issue

Instructional Method: Instructor prepares an assortment of student exercise to be done by teams as the "final exam." Topics selected for those final exercises are based on the topics which were found to be of most interest to the students. Teams record their answers on flip chart sheets and present the results to the group. Review overall learning objectives. Interactive discussion between both instructors and participants. Use overhead of basic project geotechnical phases (Site investigation, basic soil properties, etc.) to stimulate group discussion. Display overhead of lesson titles to stimulate discussion. Open the Reference Manual and point to key sections (construction, design, design examples, guide specification, inspection, integrity testing). Ask the participants to list the most important concepts and details learned in the course, lesson by lesson. List the concepts articulated by the students on the chalkboard or flip chart and summarize them to complete the course. Brainstorm on applying new knowledge and skills to problems back at participants' home office and problems not solved. Complete course critique forms.

Instruction Day: Day 5 -- AM

Time Allocation: 60 minutes

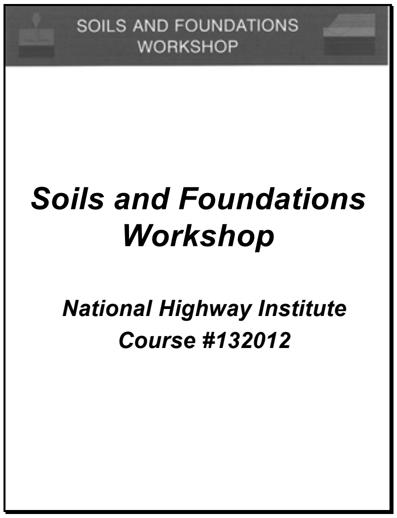
Evaluation Plan: Ask students to provide the important concepts learned in the team exercise. Instructor interacts with the teams to assess their level of learning. Interact with the participants as they list the most important concepts that, they learned during the exercise and ask clarifying questions when appropriate. End with overhead of learning objectives and discuss what students learned or did not learn. *(Use this feedback for future topics for the course, if appropriate.)*

Reference: None

LESSON 1

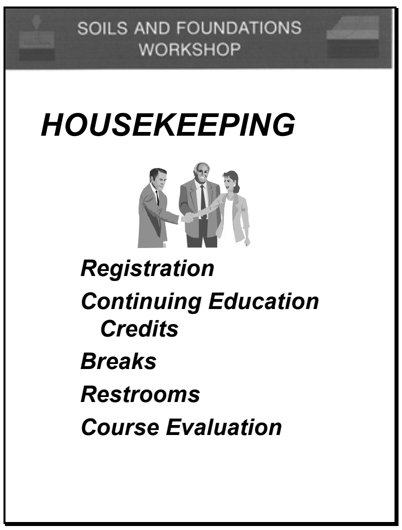
TOPIC 1

Workshop Introduction



Slide 1-1-1

Instructor places course title overhead on screen about 15 minutes prior to class start time. Interact with the state representative who will introduce both the course and the instructors.

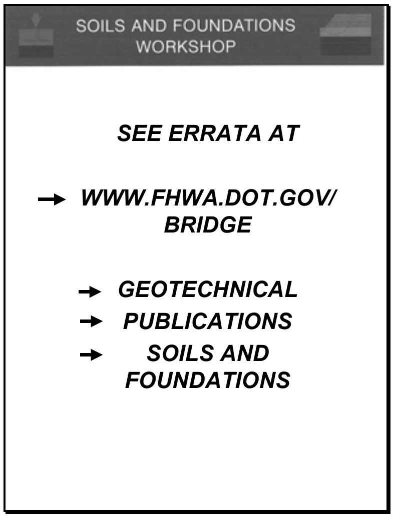


Slide 1-1-2

After the local training officer introduces the workshop, the items above should be explained to the group. All participants should be told that they should register on the NHI course form and on whatever forms the host state requires. Continuing education credits are given, and the lead instructor should point out the requirements for obtaining the credits and for registering for them. Forms are provided in the NHI packet. Emphasis should be placed on frequent breaks and the requirements that breaks shall end promptly when participants are asked to return to their seats. Locations of rest rooms (and, if appropriate, break and lunch rooms) should be pointed out. Finally, participants should be told that they will be asked to fill out a course evaluation form at the end of the course.

Slide 1-1-3

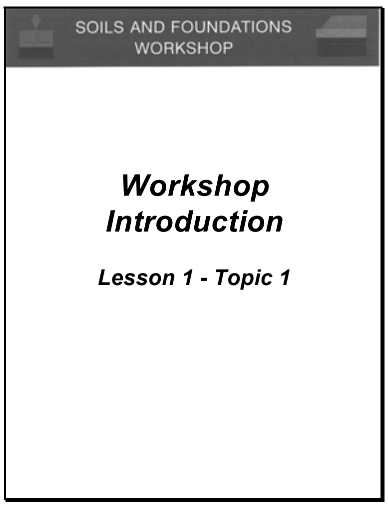
Each participant should be asked to stand and introduce himself/herself. The self-introduction should include the participant's name, affiliation (if not with the State DOT), division or unit where employed, and a few words on why he or she is interested in attending a course on soils and foundations. This activity should take 3 - 5 minutes.



Slide 1-1-4

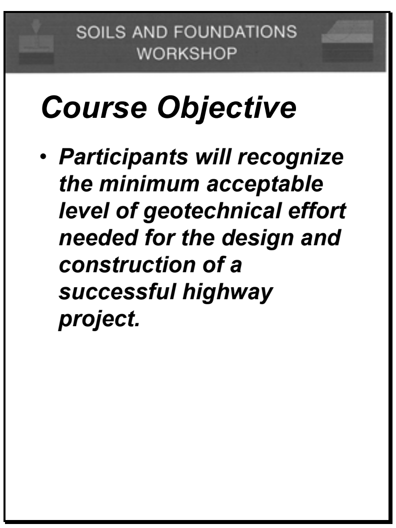
Instructor should point out to the participants to consult this web site for any errors which may be identified in the Reference manual.

At this point, a series of overheads may be shown by either the instructor or an FHWA representative to overview current features of the FHWA geotechnical program. The group need not take detailed notes as the FHWA where this information is located will be identified in the presentation.



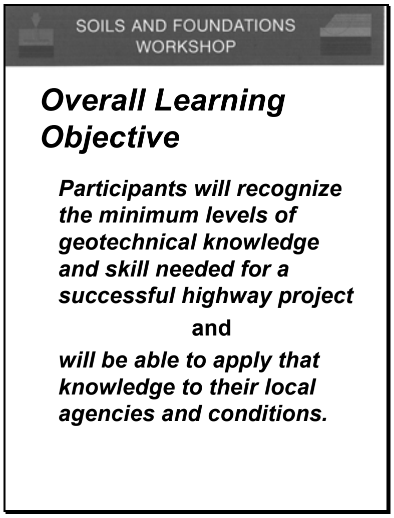
Slide 1-1-5

Explain the use of the course materials, participant workbook, and the reference manual. Invite the students to follow the course presentation and add notes in the participant manual. Explain the reference manual material will be covered at the end of each topic or lesson.



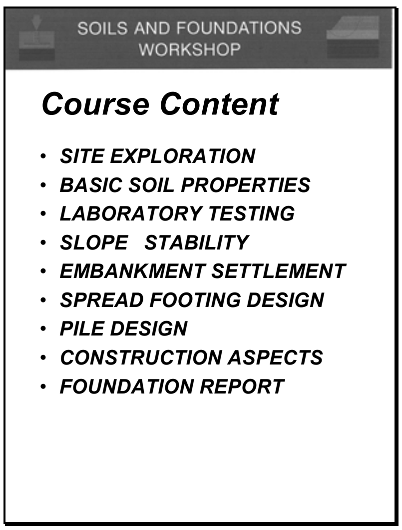
Slide 1-1-6

Define overall learning objective



Slide 1-1-7

Emphasize that the reference manual and the course contain the minimum level of geotechnical work that FHWA considers necessary for a successful highway project. The manual can be useful in establishing guidelines for in-house or consultant work.

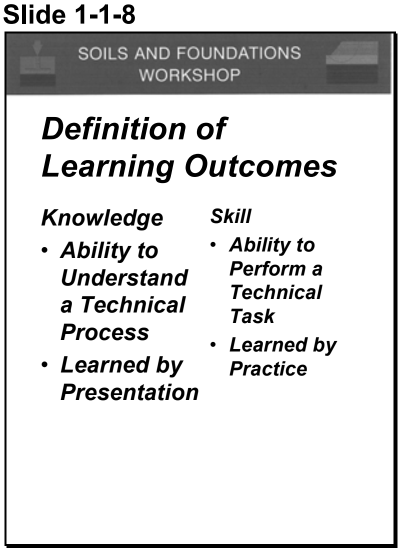


Slide 1-1-8

Instructor shows first 4 overheads.

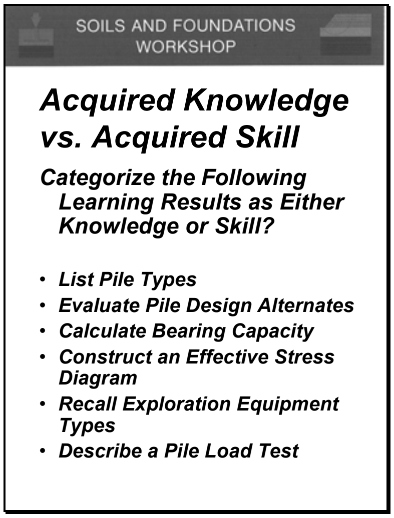
After 4th overhead displayed, ask students what they want to achieve from these course lessons.

List the answers on a flip chart, post the final result and refer back after each section to view accomplishments. Explain that the manual and course are designed to follow the geotechnical process for a typical project from beginning to end. Successful completion of each step in the process requires a certain minimum level of knowledge and skill in the topic area. A fictitious project, called the Apple Freeway, will be used to demonstrate the application concepts.



Slide 1-1-9

Explain the difference between knowledge and skill.
Then quiz students with next overhead.



Slide 1-1-10

Test students on learning concepts.

Ask the group to identify which items are knowledge or skill. Explain that basic courses such as this are weighted toward knowledge learning; more difficult specialized course are weighted toward attainment of skills.

Then show a pre-prepared flip chart sheet of other NHI geotechnical courses and the FHWA web site address where more information can be found. Post the sheet on the wall and refer to the sheet later in topic areas where more detail is available in other courses.

LESSON 1

TOPIC 2

General Overview of Geotechnical Input to Highway Projects

GENERAL OVERVIEW OF GEOTECHNICAL INPUT TO HIGHWAY PROJECTS

Lesson 1 - Topic 2

Slide 1-2-1

Explain the purpose of this initial lecture is to familiarize students with the overall geotechnical process and with the method of teaching to be used in the remainder of the course. The instructor should use this lesson to generate interest in geotechnical engineering concepts. The use of case histories is important to convince students that geotechnical issues are important for highway design and construction.

GENERAL OVERVIEW OF GEOTECHNICAL INPUT

1. Recognize the Importance of Testing, Theory, and Experience
2. Recall Basic Geotechnical Phases

ACTIVITY: ***Question-Answer***

Slide 1-2-2

Instructor explains the display of learning objectives at the beginning of each lesson and the use of question – answer to test learning.

Slide 1-2-3

Ask what geotechnical items students see in this picture; answer is stable cut and fills slopes, stable pavement foundation, smooth riding highway with no differential across culvert.

Geotechnical Participation in Project Phases

- *Planning*
  - *Prepare Terrain Reconnaissance Report*
  - *Perform Site Inspection*
- *Alternate Design*
  - *Assess Major Soil Problems*
  - *Implement Subsurface Program*

Slide 1-2-4

Next 3 slides show the geotechnical process by project phase. Note that the geotechnical units are involved in all project phases.

Geotechnical Participation in Project Phases (Cont'd)

- *Advance Detailed Plans*
  - *Complete Testing and Analysis*
  - *Submit Foundation Investigation Report*
- *Final Design*
  - *Review Final Plans*
  - *Prepare Pre-bid Geotechnical Package*

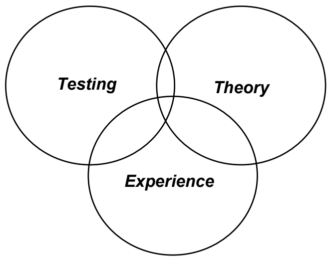
Slide 1-2-5

Geotechnical Participation in Project Phases (Cont'd)

- *Construction*
  - *Brief Project Staff*
  - *Trouble Shoot Geotechnical Problems*
- *Post Construction*
  - *Monitor Results*
  - *Participate in Court of Claims Actions*

Slide 1-2-6

After explanation of process, mention that 50% of highway claims are geotechnically related. Ask the best way to avoid geotechnical claims; answer is to follow this process in order; i.e. Do not take borings after design is finished.



Slide 1-2-7

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 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.

Terrain Reconnaissance

Slide 1-2-8

Is Terrain Reconnaissance done in the field or the office?

Use the header slides for process steps, which follow to gage how much the audience understands about the overall process.

Slide 1-2-9

Show USDA County soil map as example of office review process. Briefly discuss how such documents can provide an overview of the general ground conditions at a project site.

Site Inspection

Slide 1-2-10

After showing header ask student what they see in the following project slides 11-12

Slide 1-2-11

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 and assess stabilization methods.

Slide 1-2-12

Example of karstic sinkhole. Instructor should mention that sinkholes can be deep and contain voids or soft soils. Sinkholes represent a major problem to highway construction and need to be identified early in design.

Slide 1-2-13

Funny Slide to show what happens if you do not find sinkhole until after construction begins and have to change alignment.

Subsurface Borings

Slide 1-2-14

Ask what type of borings the audience is familiar with?

Slide 1-2-15

Show optimal conditions to perform borings (warm, sunny, no precipitation, near road, easy move-in, etc.)

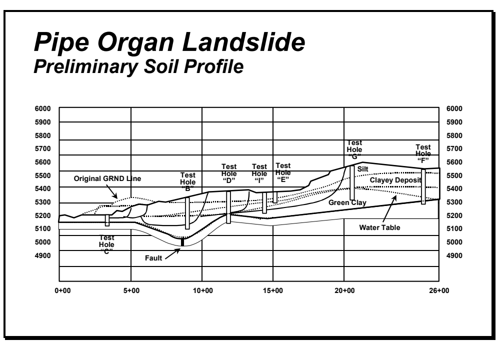
Slide 1-2-16

Show difficult site and working conditions. Stress that driller must be a dedicated professional to perform ASTM tests under difficult conditions. If they do a good job your designer will have a chance to do a good job. Spend as much time as necessary to insure audience understands how valuable these workers are!

Soil Profile

Slide 1-2-17

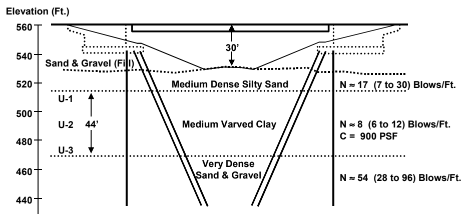
Ask who has developed a soil profile and what was the most important information which was used (answer will be boring info. so emphasize the importance again of the drillers)



Slide 1-2-18

This slide shows a rough generalized soil profile for a large landslide. Information from site inspections, geologic maps, aerial photos, and preliminary borings have been plotted on the profile. This profile will be used to make a preliminary assessment of the landslide problem and plan the detailed exploration and testing program.

Typical Final Soil Profile



Slide 1-2-19

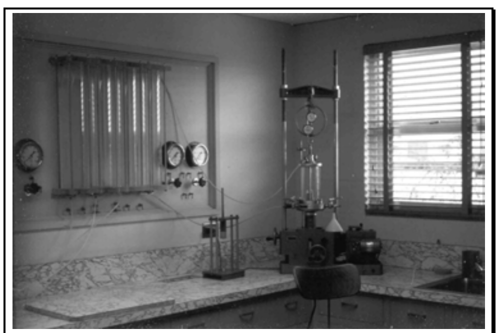
A typical final soil profile will be used to make a preliminary assessment of the landslide problem and plan the detailed exploration and testing program.

Soil Testing

Slide 1-2-20

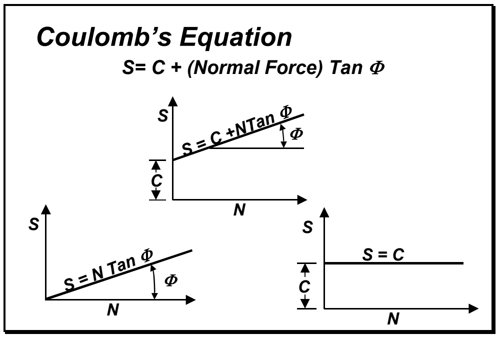
Why are soils more difficult to test than concrete or steel?

Answer to question is that soils are made of water, minerals and air, which have developed a structure from the pressures in the ground.



Slide 1-2-21

Explain that sample structure must be maintained to obtain structural soils properties for design.



Slide 1-2-22

Explain that different lab tests produce different strength results for the same soil sample depending on the test method selected.

Geotechnical Analysis

Slide 1-2-23

Ask what types of analysis the audience has performed.

Embankments
Major Design Considerations

- ***Stability***
- ***Settlement***
- ***Effects on Structure***

Slide 1-2-24

Show the main categories of analyses to be covered in the course.


Slide 1-2-25

Show stability case history (this one is a failure caused by drawdown).


Slide 1-2-26

Show settlement case history (this one is a simple approach embankment settlement). Ask if the previous stability or this settlement cost more to fix? (Answer is in life cycle cost…often the long term cost of settlement repair is much greater than stability repair)


Slide 1-2-27

Is this structure on a shallow foundation or deep foundation?

Answer is piles. But poor construction control caused piles to hang up in embankment just above 30' thick soft clay deposit. Result was 30" settlement over a period of 10 years.

Design Solutions to Embankment Problems

- ***Change Alignment***
- ***Lower Grade***
- ***Counterberm***
- ***Excavate and Replace Weak soils***

Slide 1-2-28

Introduce problem solutions for embankments and stress the need to match the solution to the problem.

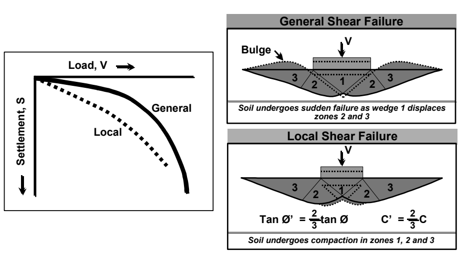
Structural Foundation Topics

- ***Shallow Foundations (Spread Footings)***
  - ***Bearing Capacity***
  - ***Settlement***
- ***Deep Foundations***
  - ***Load Capacity***
  - ***Settlement***
  - ***Negative Skin Friction***

Slide 1-2-29

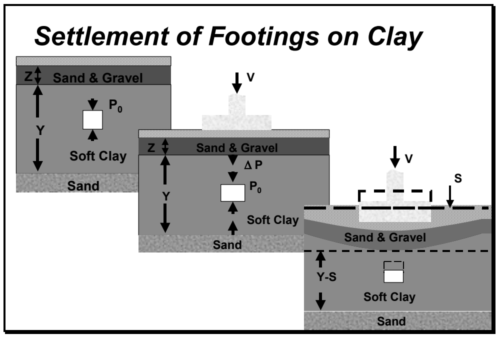
Structural topics only considered after the designer has evaluated stability and settlement of the embankment.

Shallow Foundation Failure Mode



Slide 1-2-30

Theoretical aspects of bearing capacity less important than the practical aspects (depth and extent of failure, etc,)



Slide 1-2-31

Settlement consists of both magnitude and time considerations; often maintenance is more concerned about time as this increases number of maintenance visits and the cost.

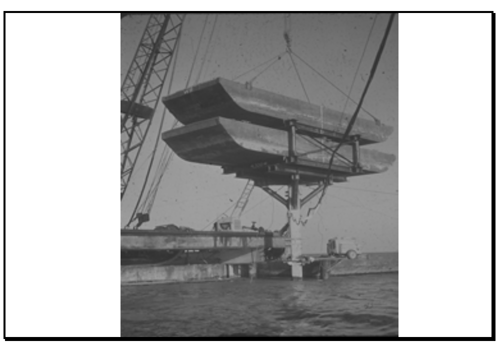
Individual Piles

Method of Estimating Load Capacity

- ***Load Test***
- ***Dynamic Formula***
- ***Static Analysis***

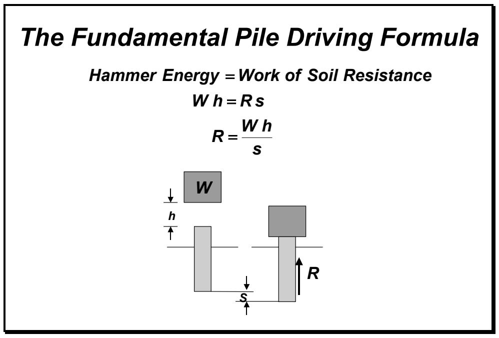
Slide 1-2-32

Deep foundation capacity can be found by 3 methods; what do the first 2 have in common, which the third does not have? (Done in the field not the office)



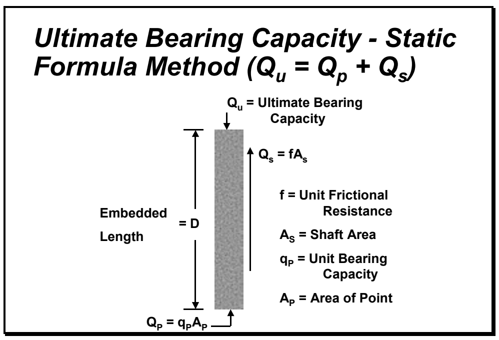
Slide 1-2-33

Explain costs and possible danger of load testing.



Slide 1-2-34

Explain basic assumption of a Newtonian impact for the dynamic formulas and how this is incorrect.



Slide 1-2-35

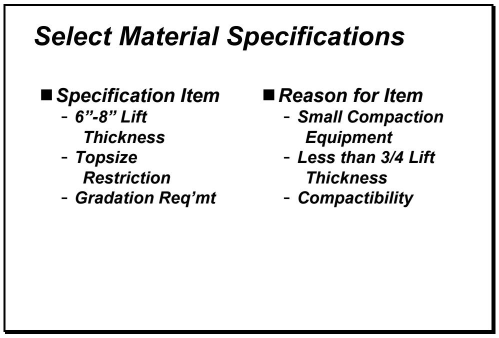
Explain how designers must rely on prediction of deep foundation capacity from soil data on the vast majority of highway projects.

Construction Aspects

- **_Monitoring Construction Operations_**
- **_Quality Assurance_**

Slide 1-2-36

Introduce construction monitoring and quality assurance for both embankments and foundations.

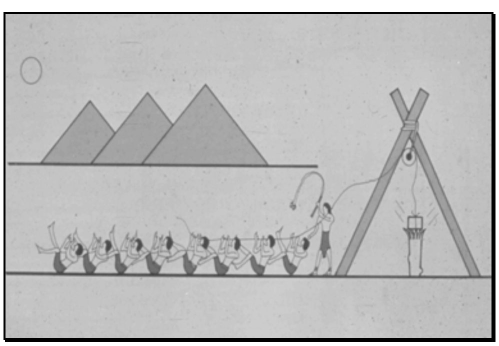


Slide 1-2-37

Show how specifications are the backbone of embankment control.

Slide 1-2-38

Show case history of poor embankment construction practice. (This one uses degradation shale with no top size in an interstate embankment, which failed after 5 years service.)



Slide 1-2-39

Humorous slide depicting the current state of pile construction monitoring in some highway agencies. After showing slide, ask the group what methods are used by their highway agency to monitor pile construction operations.

Slide 1-2-40

The number one priority in monitoring construction operations is the use of a trained inspector.

PROJECT SUCCESS

Cooperation Between Design & Construction

Slide 1-2-41

Stress need for cooperation and communication.

GENERAL OVERVIEW OF GEOTECHNICAL INPUT

1. Recognize the Importance of Testing, Theory, and Experience

2. Recall Basic Geotechnical Phases

ACTIVITY: Question-Answer

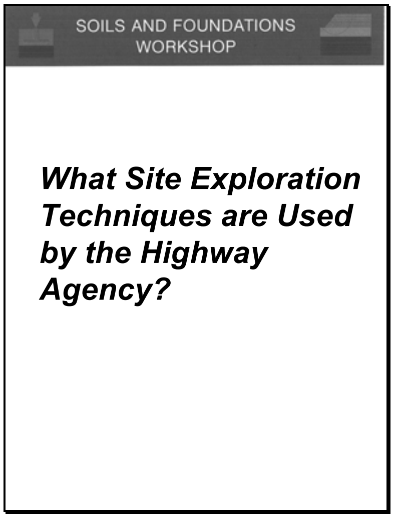
Slide 1-2-42

End presentation with a review of the objectives. Then ask students to open reference manual to Chapter 1 and briefly review the chapter contents.

LESSON 2

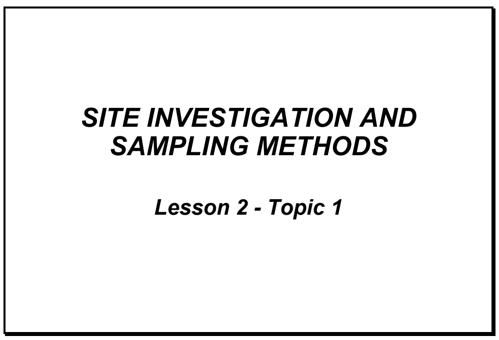
TOPIC 1

Site Investigation and Sampling Methods



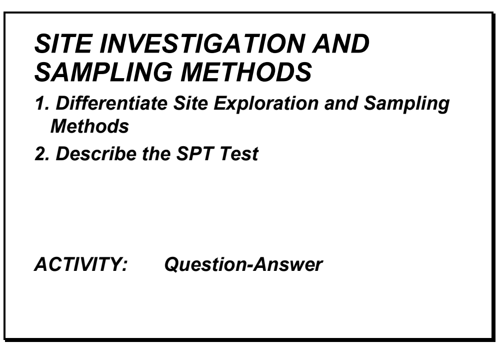
Slide 2-1-1

Begin lesson 2 topic 1 by asking the group to name the site exploration techniques that the agency now uses for highway projects. The instructor should write the responses on a flip chart sheet. At the end of lesson 2 (after the DOT representative presentation), ask the group to add to the list from what was just presented.



Slide 2-1-2

Ask for a show of hands on who has seen subsurface explorations in the field. Note that this lesson contain very basic material which may be known by some in class but is needed to insure that all students have the proper basis for more advanced concepts presented later in the course.



Slide 2-1-3

State objectives.

The Six Stages of a Project

1. ***Enthusiasm***
2. ***Disillusionment***
3. ***Panic***
4. ***Search for the Guilty***
5. ***Punishment of the Innocent, and***
6. ***Honor and Praise for the Non-Participants***

Slide 2-1-4

Funny slide relating geotechnical investigation to what can happen. Punch line is that after blaming the geotechnical engineers, the governor shows up to cut the ribbon and take credit for the new road (honor and praise to the non-participants)

Purpose of a Site Investigation

- ***Assess Suitability of Site for Proposed Project***
- ***Enable Adequate and Economic Design***
  - ***No Failures - No Conservatism***
- ***Foresee and Provide for Construction Problems that may Arise (Reduce Claims)***

Slide 2-1-5

General concepts

Foundation Engineer

Slide 2-1-6

Funny slide

Communicate and Coordinate

Selection, Design and Construction of a Safe, Cost-effective Foundation Requires Good Communication and Coordination Among Engineers, Geologists, Drillers, Structural Engineers, Roadway Engineers, and Construction Engineers

Slide 2-1-7

Reinforce concept from previous lecture and how this applies to site investigation.

Site Investigation Phases

- ***Site Reconnaissance***
- ***Detailed Investigation***
- ***Construction Observation and Monitoring***

Slide 2-1-8

Phases to be covered in lecture.

Site Reconnaissance

- ***Where Site Located***
- ***Geologic Maps-Topographic Maps-Well Logs***
- ***Air Photos***
- ***Nearby Boring Data***
- ***Site Inspection (With Bridge Designer)***

Slide 2-1-9

Emphasize site recon is both office and field related activity.

Site Reconnaissance (Cont'd)

- ***Equipment Needed to Access Site***
- ***Basic Design Decisions***
- ***Prepare Site Reconnaissance Report***

Slide 2-1-10

Stress need for geotechnical engineer to do recon.

Slide 2-1-11

What do you see in this picture which should be noted in the site investigation report?

Answer is the boulders in the pile alongside the excavation. Mention that borings can miss boulders

Slide 2-1-12

Ask what should be noted here. (Answer is settlement of approach)

"If you do not know what you are looking for in site investigation, you are not likely to find much of value."

R. Glossop-8th Rankine Lecture

Slide 2-1-13

Read quote and explain importance.

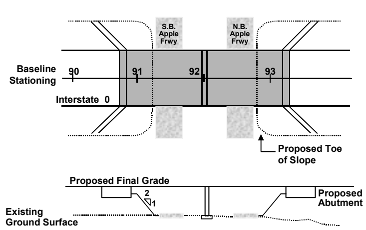
Detailed Investigation

- ***Boring ➔ Sampling ➔ Testing***
- ***Develop Soil Profile***
- ***Get Parameters for Final Design***
  - ***Embankments***
  - ***Foundations***
- ***Data for Construction***

Slide 2-1-14

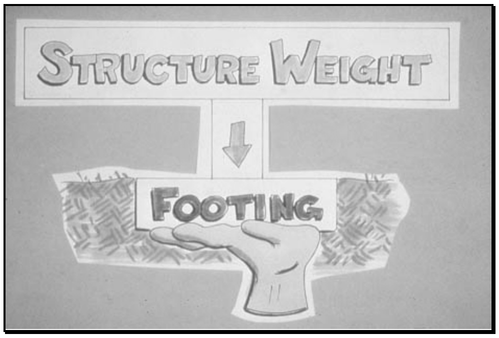
The work done is a site investigation must provide an adequate amount of information for both design and construction. The planning of this work should be done by an engineer who is familiar with design and construction uses of the subsurface data. Coordination with others involved in the design process will produce the proper amount of relevant site information.

Preliminary Bridge Layout



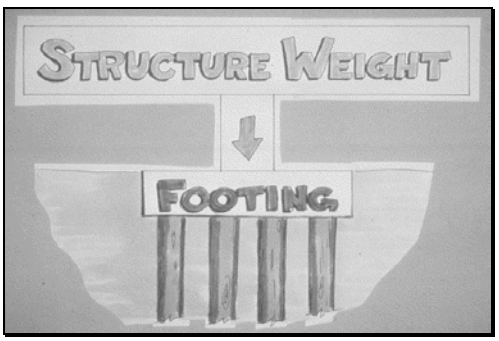
Slide 2-1-15

Show initial typical plan which would be used to layout a site investigation for a proposed structure. Note that receipt of such a plan is usually the first step in beginning a detailed site investigation. This layout usually provides information about critical locations to be explored, site access, available survey lines, and rough dimensions of the embankment.



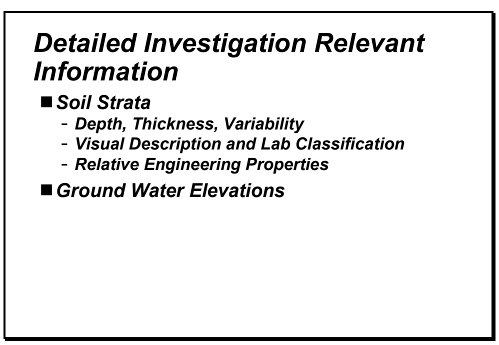
Slide 2-1-16

Relate possible use of shallow foundations to investigation requirements. Mention that the bearing capacity of spread footings is controlled primarily by the soils located a short distance below the footing. Therefore continuous samples are usually taken for the top 15' to better define the bearing conditions.



Slide 2-1-17

Relate possible deep foundation to investigation requirements. Stress that coordination with other units such as the hydraulics unit in the case of potential scour situations, is necessary to insure that boring depth are adequate for foundation design.



Slide 2-1-18

Describe data to be collected.

Detailed Investigation Relevant Information (Cont'd)

- ***Rock***
  - ***Depth to Rock***
  - ***Rock Type***
  - ***Rock Quality (RQD, Weathering, Jointing, Joint In-filling)***
  - ***Compressive Strength***

Slide 2-1-19

Describe data to be collected.

Exploration Methods and Equipment

Slide 2-1-20

Header slide to introduce discussion on equipment.

Instructor should substitute slides of local equipment if possible.

The objective of showing the wide variety of equipment, which follows, is that there is no excuse not to take borings at any site; equipment exists for all sites and conditions.

Slide 2-1-21

Hand auger or other shallow work


Slide 2-1-22

Tripod rig moved by hand or by helicopter.

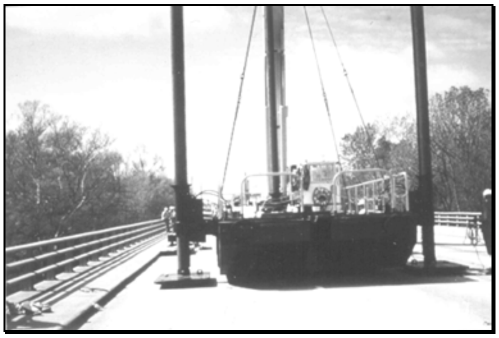
(Funny slide. ask who is geotechnical engineer. Answer is man on right)


Slide 2-1-23

Minuteman rig can be backpacked into remote site.
Able to bore to 200' depth.


Slide 2-1-24

Skid rigs are compact, full size drill rigs which are used at numerous off road sites. These rigs require transport to the project site but can be winched to locations that are not accessible to truck mounted rigs.

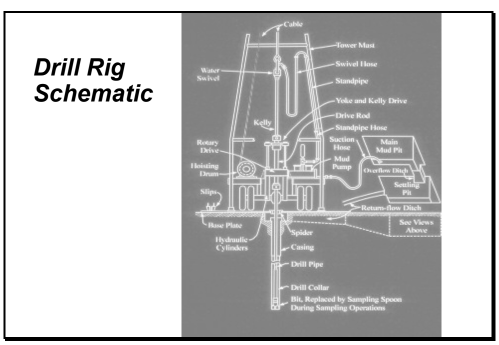


Slide 2-1-25

Jack up barge and rig used by North Carolina DOT for over water work. The legs of this barge are about 40’ long and are deployed after the barge has been moved into position over a borehole location.

Slide 2-1-26

Jack-barge and rig deployed in a river. Note that rig is now stationary and will not be affected by currents of tides. A stationary position greatly simplifies the procedure for qualify undisturbed sampling and in-situ testing.



Slide 2-1-27

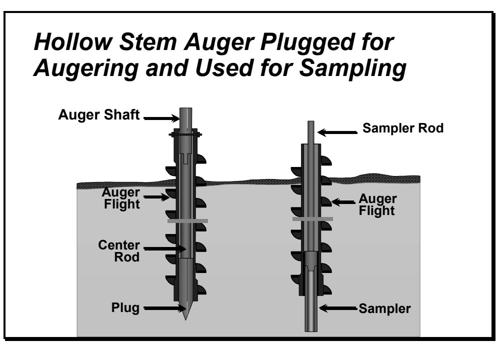
Schematic only shown to illustrate the complexity of the mechanical workings of a drill rig. Bottom line: the drillers must qualified to be an equipment operator as well as a soils technician. Stress the difficulties of the drilling job.

Slide 2-1-28

Driven casing hole advancement.

Slide 2-1-29

Hollow stem auger hole advancement.



Slide 2-1-30

Schematic of hollow stem process.

Soil Sampling and Testing Methods

Slide 2-1-31

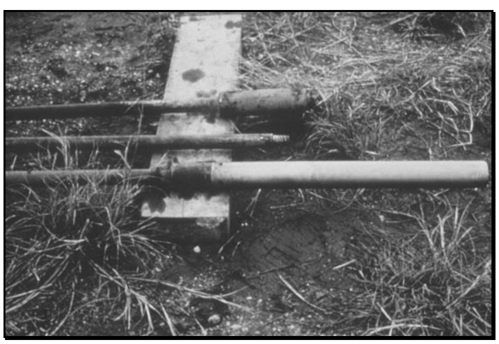
Introduce soil sampling and field testing; the key point in this section is to stress that the procedures used in this field work are controlled by standards developed by groups such as AASHTO or ASTM. Adhering to these standard procedures is time-consuming but absolutely necessary to insure the results of soil sampling and testing are valid. Shortcuts or improper techniques can result in site information that will lead to poor design. The DOT can insure the quality of site work down by in-house staff through periodic training. However the capabilities of site investigation contractors is more difficult to assess and their work requires the use of qualified inspectors by the DOT.

Cohesive Soils

"Undisturbed" Tube Samples
(Shelby or Piston Sampler)

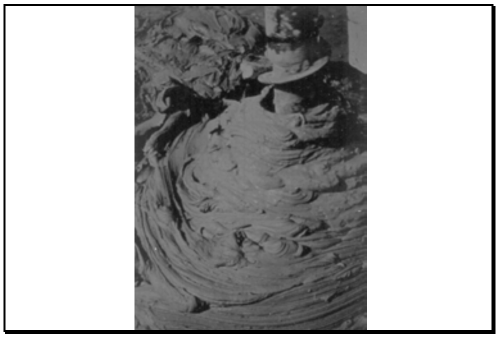
Slide 2-1-32

Cohesive sampling techniques.



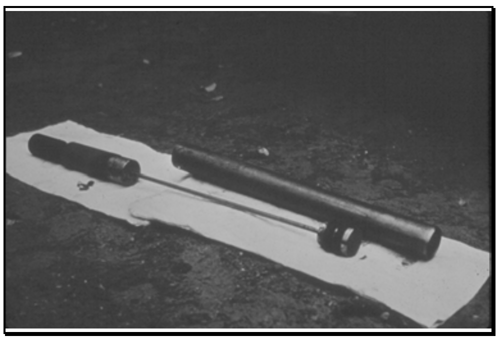
Slide 2-1-33

Explain basic equipment for sampling cohesive soils with a Shelby tube. Important items to note are preparation of the hole prior to insertion of the tube, the need for a slow, steady press of the tube, and the proper length of the press. Note in this slide that the top of the tube typically is connected to the drill rod by a head which extends into the tube about 4". Therefore the maximum length of press must be at least 4" less than the tube length to prevent sample disturbance.



Slide 2-1-34

Explain that very soft soils require special sampling techniques to prevent the sample from falling out of the tube during withdrawal. Ask if anyone knows how to perform this operation.



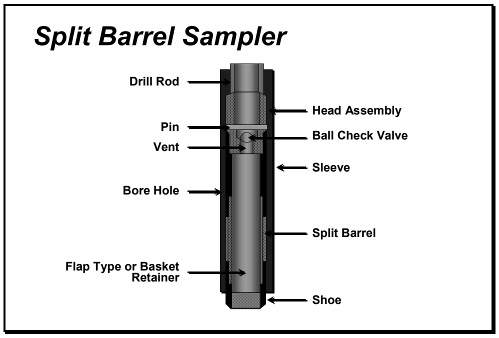
Slide 2-1-35

Show stationary piston sampler, which is used to sample very soft soils. Briefly explain that the sampler has separate rods, which are connected to the piston (inner rod) and the tube (outer rod). The sampler is lowered into the hole with the piston at the bottom of the tube. The outer rod is used to advance the tube as the piston remains stationary on the top of the soil sample. After the press is complete the piston is locked and the tube is withdrawn. The piston provides a vacuum to hold the soft material in the tube during withdrawal.

"Sampling of Granular Soils Use Split Barrel Sampler"

Slide 2-1-36

Introduce sampling of granular soils



Slide 2-1-37

Explain how split barrel sampler works and possible problems to watch out for during inspection of drilling operations such as; damaged drive shoe which would cause artificially high blow counts or removal of the ball check valve which would cause softening of the soils to be sampled or poor recovery of soil in the sampler which could be due to clogging of the shoe and result in high blow counts.

Slide 2-1-38

Show how sample retained in spoon. Mention that the sample is then transferred into a plastic bag and placed in a jar or other container, which is labeled and sealed to prevent loss of moisture.

Slide 2-1-39

Show care and transportation of samples to preserve properties.

The Standard Penetration Test (AASHTO T-206, ASTM D-1586)

The Standard Penetration Test (SPT)
2" O.D. Sampler
140# Hammer/30" Drop
N = Blows/Foot

Slide 2-1-40

Explain the SPT standard test.

Slide 2-1-41

Picture of safety hammer with cathead and rope drop. Explain that automatic hammer systems are also available.

Use of SPT "N" Values

- ***Granular Soils***
  - ***Estimate Friction Angle ϕ***
  - ***Estimate Settlement***
- ***Cohesive Soils***
  - ***Only Crude Estimate of Cohesive Strength***
  - ***Do Not Use for Final Design***

Slide 2-1-42

Describe use of N values

Relative Density of Sand Based on SPT N -Values

Slide 2-1-43

Relate granular soil density to N.

Consistency of Cohesive Soils Based on SPT N-Values

N Blows/Foot	***Consistency***
Below 2	***Very Soft***
2 – 4	***Soft***
5 – 8	***Medium***
9 – 15	***Stiff***
16 – 30	***Very Stiff***
Over 30	***Hard***

Slide 2-1-44

Relate cohesive soil consistency to N. Mention that N. values in cohesive soils are not a good indicator of soil strength. Then before showing the next slide, ask what are some sources of error in the SPT test?

SPT Test - Common Errors

- ***Damaged Drive Shoe***
- ***Variation in Hammer Fall***
- ***Effect of Overburden Pressure***
- ***Plugging End of Sampler***
- ***Hollow Stem Auger Quick Condition***
- ***Careless Work by Drill Crew***

Slide 2-1-45

Do not explain obvious errors. Focus on need for competent drillers to perform test and the Po effect.

Advantage of SPT Test

- ***Very Economical Test***
- ***Provides Sample for Soil Classification***
- ***Long Service Life of Equipment***
- ***Vast SPT Data Base***
- ***Numerous Empirical Correlations with SPT***

Slide 2-1-46

Review the need for competent drillers to perform test. At this point the instructor should encourage the DOT to provide training to their field staff on a routine basis.

Gravels - What to do?

- ***SPT may not be Dependable***
- ***Can Use Oversize Sample Spoon***
- ***Can Use Dynamic Cone for Correlation to SPT Test***

Slide 2-1-47

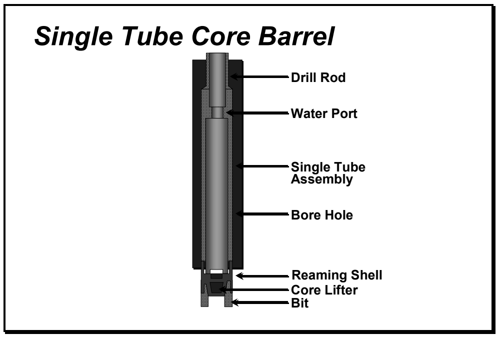
Show special issues in gravels.

Rock Sampling

Slide 2-1-48

Introduce rock-sampling techniques.

Stress that new developments in equipment have vastly improved our ability to obtain high quality rock samples.



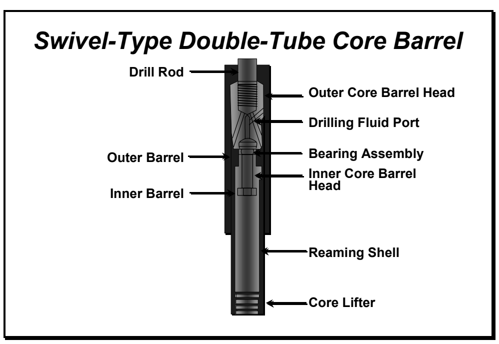
Slide 2-1-49

Describe old type barrel, how the drilling fluid passes between the core and inside of the barrel, the problems with loss of core due to the wash water, and what was considered good recovery; i.e. 50%. Also recommend that only double tube or better core barrels be used for DOT work to provide adequate rock information.

Slide 2-1-50

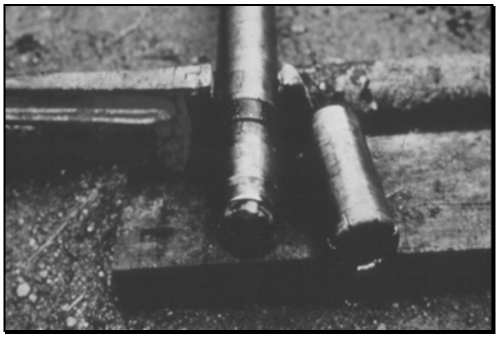
What is wrong with this method of removing rock core from the sampler?

Answer is that core is usually fragmented and any attempt to remove from barrel should be made into a core box so the sample is retained intact as possible.



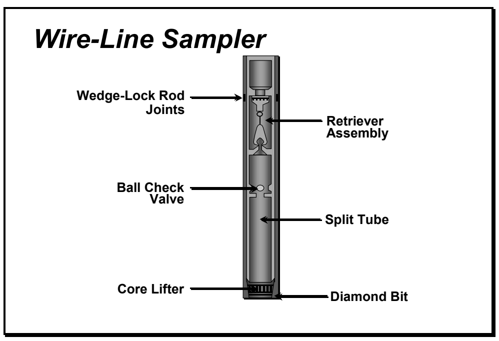
Slide 2-1-51

Explain the workings of a double tube core barrel. Note that the swivel type barrel shown here is preferred over a rigid barrel, as the swivel type permits the inner barrel to remain stationary while the outer barrel rotates. This design minimizes any abrasion of the core due to the rotation of the inner barrel.



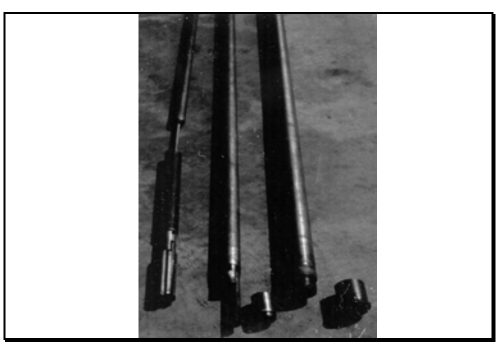
Slide 2-1-52

Show the component equipment for the double tube barrel and mention that industrial diamonds are used on the bit. Also mention that more sophisticated rock coring equipment such as triple barrels now exist.



Slide 2-1-53

Describe a wire line device and how time is saved in core extraction.



Slide 2-1-54

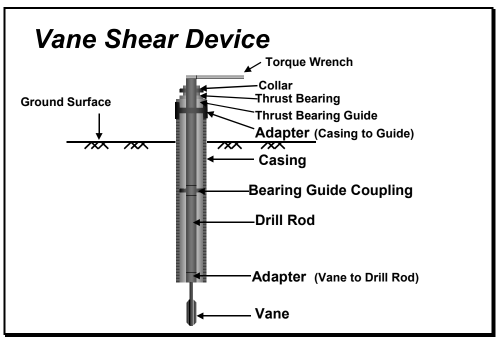
Show the wire line equipment.

In-Situ Testing

- ***Vane Shear Test***
  - ***Clays, Silts, Peats***
- ***Static Cone Penetrometer***
  - ***Clays, Silts, Sands***
- ***Pressuremeter***
  - ***Clay, Weak Rock, Sand***

Slide 2-1-55

Introduce insitu testing.



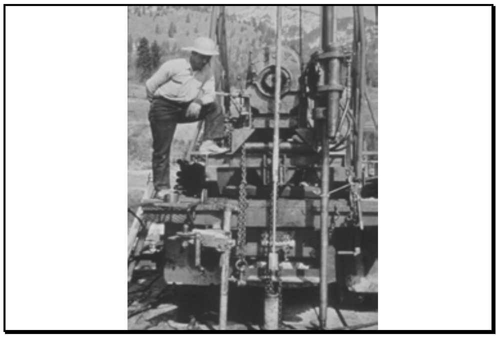
Slide 2-1-56

Describe vane shear concept.

Slide 2-1-57

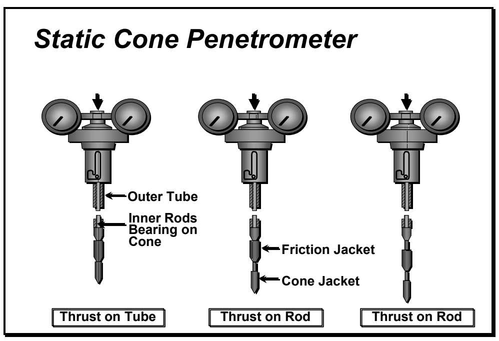
Show vane shear blades.

Ask students if large blade used in soft or hard soils.



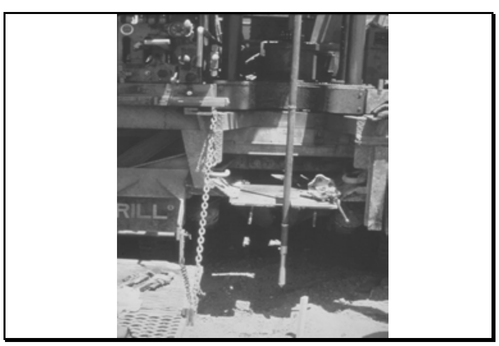
Slide 2-1-58

Show vane being inserted into the borehole. Note that the vane is extended down a defined distance below the bottom of the drilled hole and the test performed. The vane is then removed, the hole drilled deeper, and the vane test repeated at the new depth.



Slide 2-1-59

Show a basic cone penetrometer schematic and explain concept. Note that cone testing has evolved in the past decade to include special devices to measure pore pressure or soil dynamic properties. Refer students to the FHWA Site Investigation course for detail.



Slide 2-1-60

Show cone insertion into ground and importance of reaction force to cause cone penetration.

Minimum Exploration Program for Structure Sites

- *How Much Exploration?*
- *How Many Borings?*
- *How Deep Should Borings Penetrate?*
- *How Often to Sample?*
- *When to Measure Water Levels?*
- *Driller's Responsibilities?*

Slide 2-1-61

Introduce questions for discussion. Ask students to consider these items which will be covered later; both in general by the instructor and specific to agency policy by the guest speaker from the agency.

Subsurface Exploration by Drilling Contractors

- *Clearly Define Boring Procedures, Location and Depth Criteria*
- *Assign a Driller from the Highway Agency to Inspect Field Drilling and Sampling Operations*

Slide 2-1-62

Reinforce the need to obtain quality work from drilling contractors by controlling the operation.

SOILS AND FOUNDATIONS WORKSHOP

How Much Exploration?

Points to remember

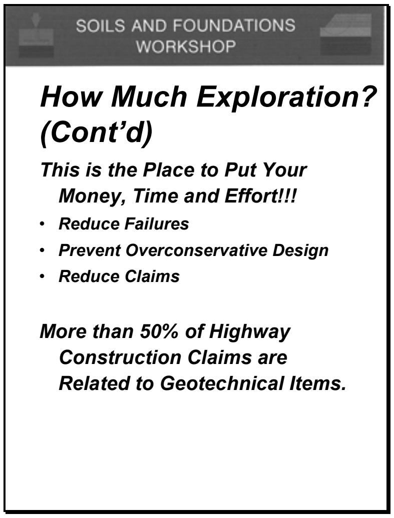
- *Boring Cost <<< Bridge Cost*
- *2.5″ Diameter Boring ≅ $ 12″ Diameter Pile*

Rule of Thumb

- *Cost of Adequate Site Investigation is 1% to 2% of Construction Costs*

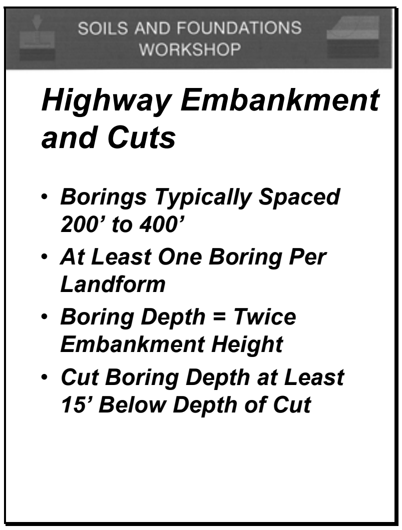
Slide 2-1-63

"How Much" transparencies used to convince students of the need to get enough data for a good design.



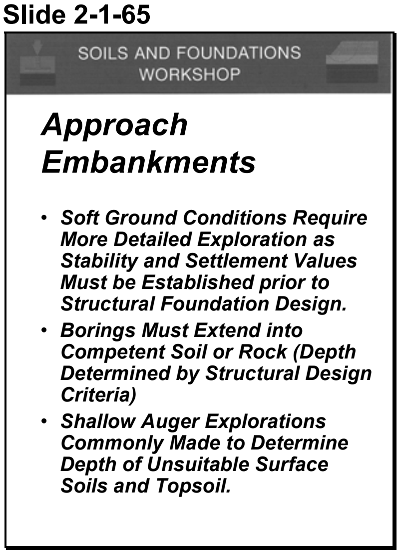
Slide 2-1-64

"How Much" transparencies used to convince students of the need to get enough data for a good design.



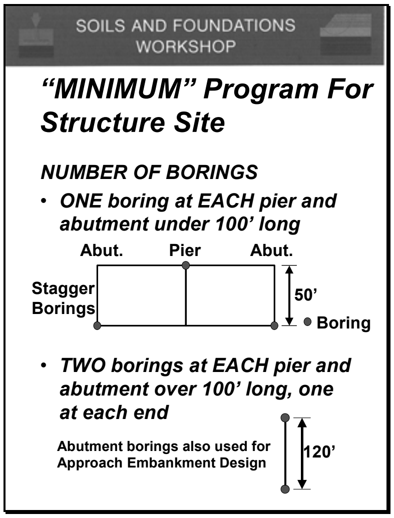
Slide 2-1-65

Begin minimum guidelines for boring and sampling. Note that the depth of cut refers to the elevation at the lowest ditch line of the cut section and not the centerline grade.



Slide 2-1-66

Carefully explain the difference between approach embankment needs and routine highway embankment needs.

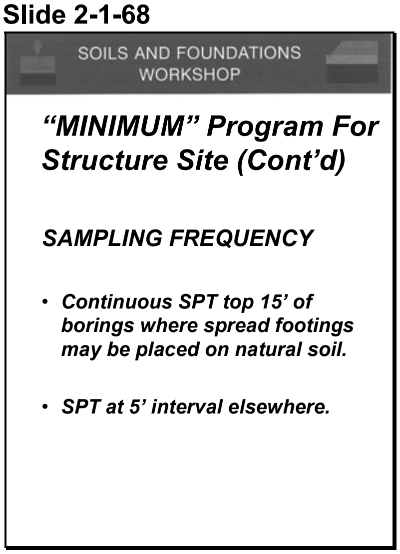


Slide 2-1-67

Explain the reasons for staggering the single borings is to obtain an indication of lateral variation of subsurface conditions. Also stress the need for coordination of highway and structure borings so the both groups do not take duplicative borings. In general the borings for approach embankment should be detailed enough to meet the needs of the structure design.

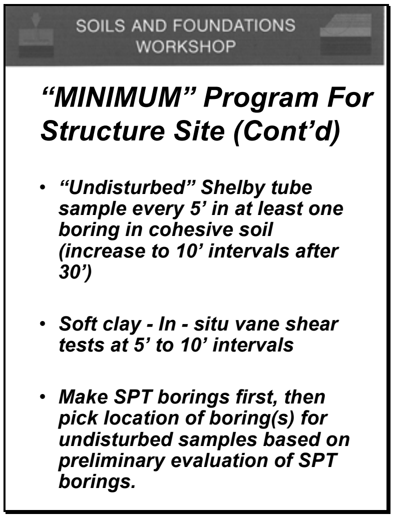
Slide 2-1-68

Contrast the criteria for the structure design needs with the embankment criteria. Note that the depth of a proposed boring is difficult to determine if no existing information is available at the site. Agencies should establish blow count criteria for boring minimum depth rather than simply asking drillers to drill to predetermined depth at all locations.



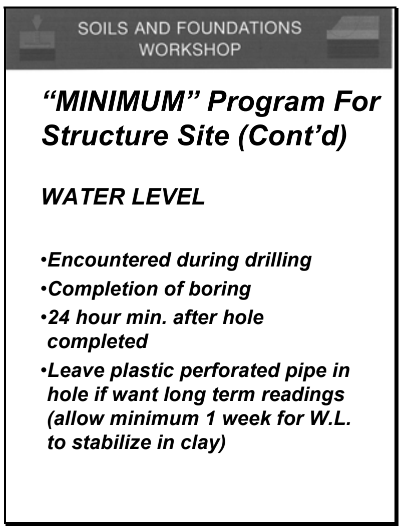
Slide 2-1-69

Note that shallow foundations place high stresses on the soil near the base of the footings. Then layers of poor materials can present major problems for the use of shallow foundations. Continuous samples taken near the footing elevation provide the necessary information for confident design.



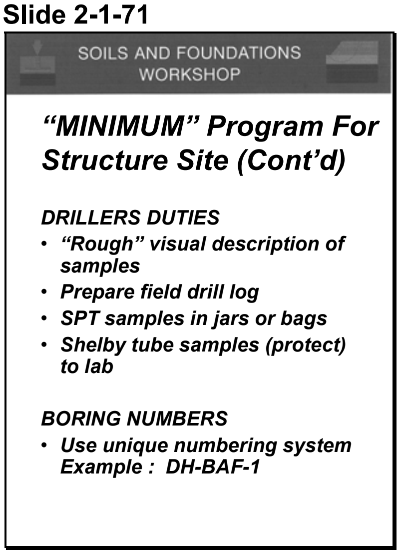
Slide 2-1-70

Note that the cost of undisturbed sampling and in-situ testing is much greater than the cost of an SPT sample. A good practice is to perform the SPT sample holes first and then decide if more expensive exploration are needed and if so where is the best location.



Slide 2-1-71

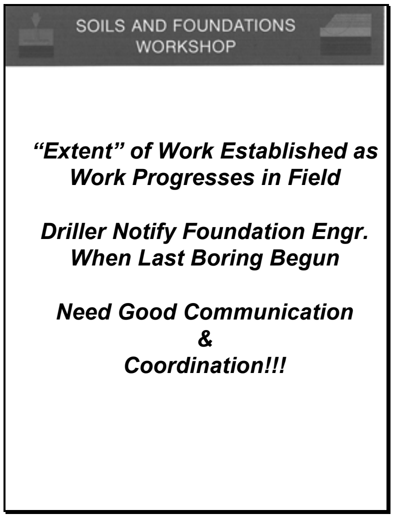
Water level is very important to determine both for embankment and structure design considerations. Additional information about water level is available from other sources such as local well records or ground water resources bulletins which can help to define the seasonal fluctuation of the area water levels.



Slide 2-1-72

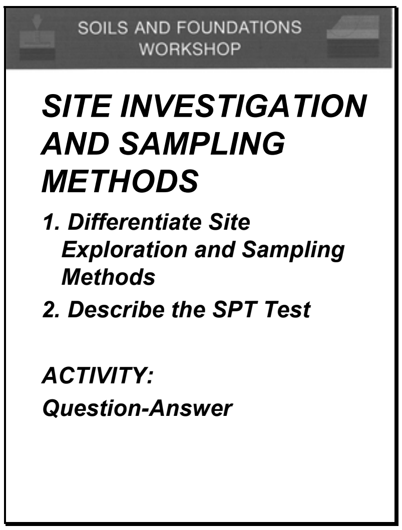
The drillers duties may be shared by a field geologist who is assigned to the rig. Students should be aware that the drillers primary duties include running the rig and doing all the operations associated with the ASTM standards for drilling and sampling.

Also the boring number issue is more important than the casual observer would guess because the duplication of boring numbers can cause major confusion in project design and construction.



Slide 2-1-73

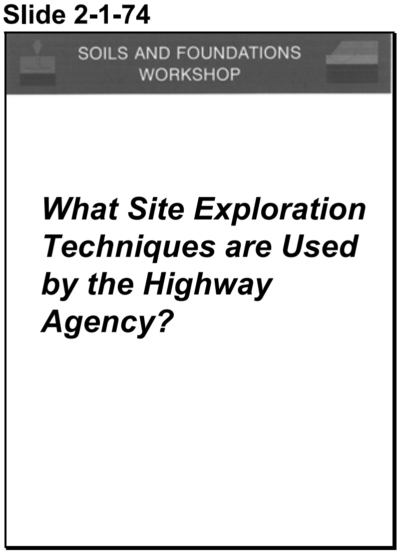
Good communication between field crews and design can pay big dividends in getting the right amount of information with the least time and effort expended. No drill crew wants to move out of a difficult site and then be asked to return a short time later because enough data was not obtained the first time.



Slide 2-1-74

Repeat objectives.

Introduce the state representative who will present agency-specific information on site investigation. After the presentation is complete, thank the presenter then show the following overhead.



Slide 2-1-75

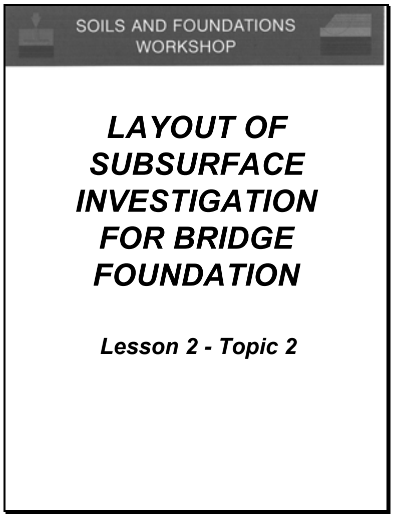
SHOW THIS OVERHEAD AFTER THE STATE PRESENTATION

Ask the group to add other site investigation techniques to the flip chart prepared at the beginning of the topic.

LESSON 2

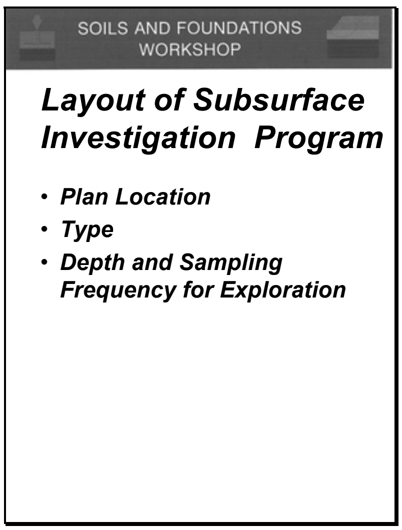
TOPIC 2

Layout of Subsurface Investigation for Bridge Foundation



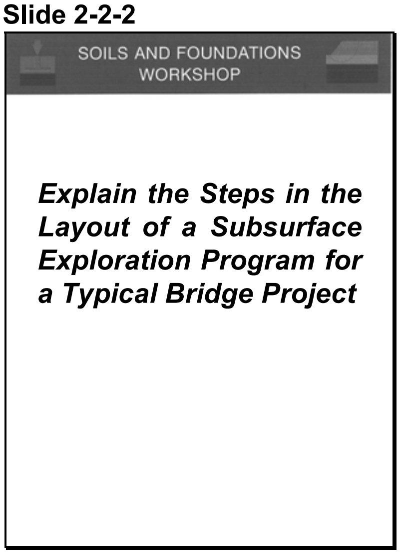
Slide 2-2-1

Instructor introduces the Apple Freeway problem and explains concept of the serialized Apple Freeway problem is to tie geotechnical concepts in each lesson into a project design. The students will help the instructor design the Apple Freeway by providing pertinent information which was learned in the lesson. The first step in the project is the site investigation.



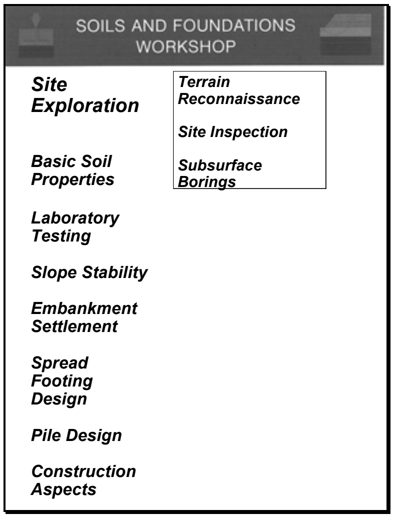
Slide 2-2-2

Ask the students to recall the guidelines for these items which we just went over in the lesson. Ask the group what information would be used from a plan location to establish a site investigation; ask similar questions for type and depth and sampling frequency.



Slide 2-2-3

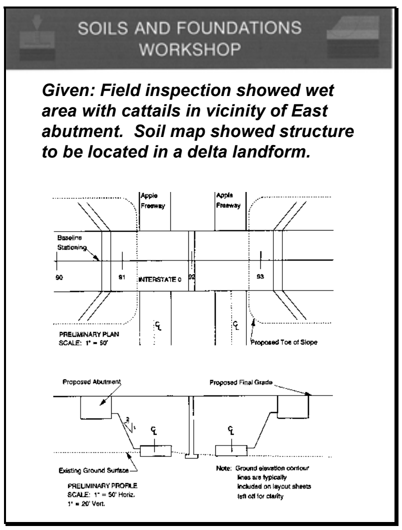
Ask the students this question which should evoke the response that we use terrain reconnaissance information, site inspection information and preliminary information about the design to plan exploration layout.



Slide 2-2-4

Then show the introductory overhead which will be used to track the progress of the Apple Freeway design. Ask the group to apply their site investigation knowledge to layout a subsurface exploration program for the project shown on the next overhead.

This is the first test of learning and should be done by the group rather than by asking individuals.

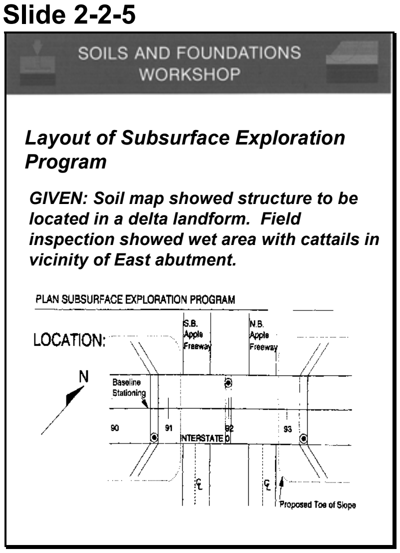


Slide 2-2-5

Display this overhead, read the given information and ask the students to plan the exploration program.

The instructor should begin use of the flip chart at this point to record group answers. Draw the plan view roughly at the top of the flip chart sheet prior to asking and recording answers below the plan. Do this neatly as you will want the student team to later record neatly and explain answers to subsequent exercises on flip chart sheet.

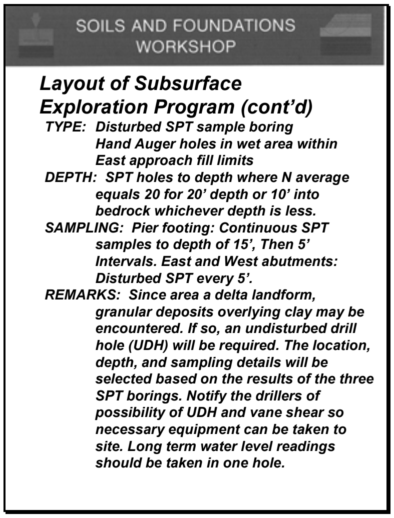
After recording the information, post the sheet on the wall of the room in such a location that later sheets of exercises can be placed sequentially to build the project design.



Slide 2-2-6

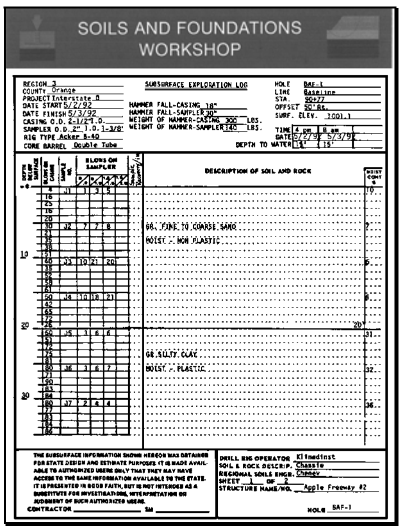
After the student responses are listed, ask the students to open the reference manual to the Apple Freeway site exploration problem at the end of Chapter 2. Summarize how you used the concepts in your thought process to arrive at the solution shown here. Compare the results here to the student solution and add any important items left out to the flip chart sheet. Then walk the students through the other pages of the reference manual which complete the problem. Use the following overheads to make important points.

Please refer to the end of the lesson for a full size version of this slide.



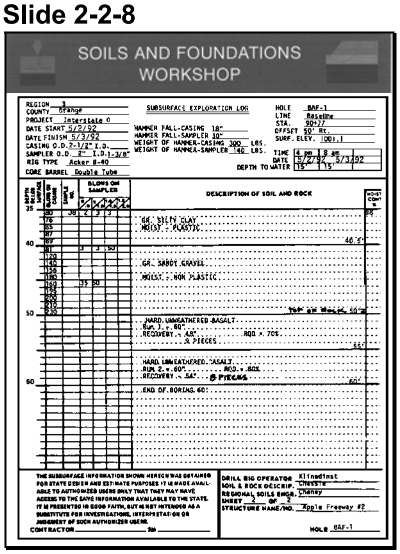
Slide 2-2-7

Please refer to the end of the lesson for a full size version of this slide.



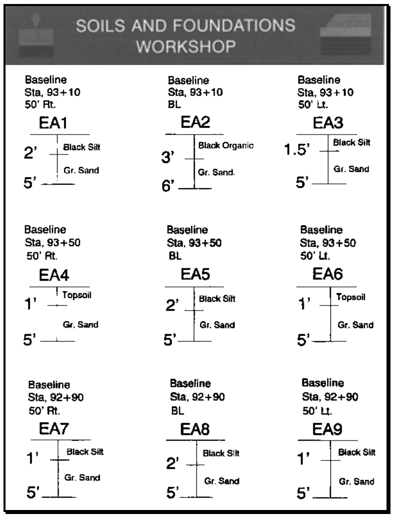
Slide 2-2-8

After describing the make-up of the log form (location, elevation, water table, penetration data, visual data, etc.) ask the group to give you the SPT N value for one of the samples. Ask what the change in the SPT value would be if the sampler had been driven 24" and we had 4-6" blow counts instead of 3-6" counts. Impress on the students again that the definition of N is the number of blows to advance the sampler from a penetration of 6" to a penetration of 18". Also mention that the field moisture contents shown here are not common but can be taken by the Speedy method.



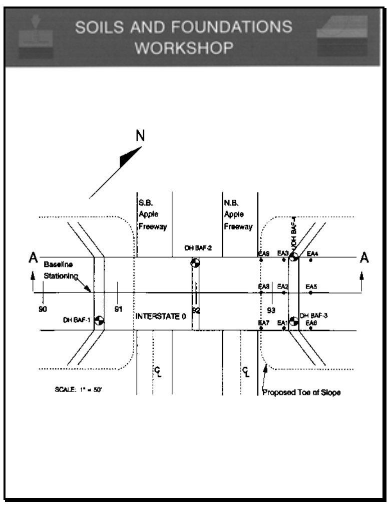
Slide 2-2-9

Continue with the log description of sheet 2 and summarize the soil profile at the Apple Freeway site (sand over clay over till over rock). Note that the other borings showed the same profile. Also ask the students to turn to the last boring log, BAF-4, note that boring was taken as an undisturbed sample hole and point out the vane shear test locations on the log sheet.



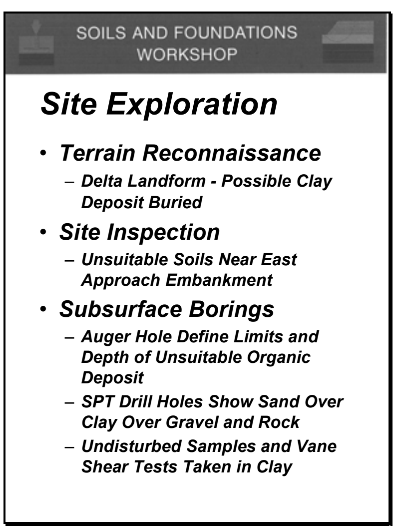
Slide 2-2-10

Ask the group how a designer would use the results from auger borings for this project site. Then explain how auger results are used to estimate quantity of unsuitable removal by the designer and then plotted on the highway cross-sections for the field inspector to use to control excavation limits.



Slide 2-2-11

Show the final boring plan which should be transmitted to the designer with the final logs as soon as possible.



Slide 2-2-12

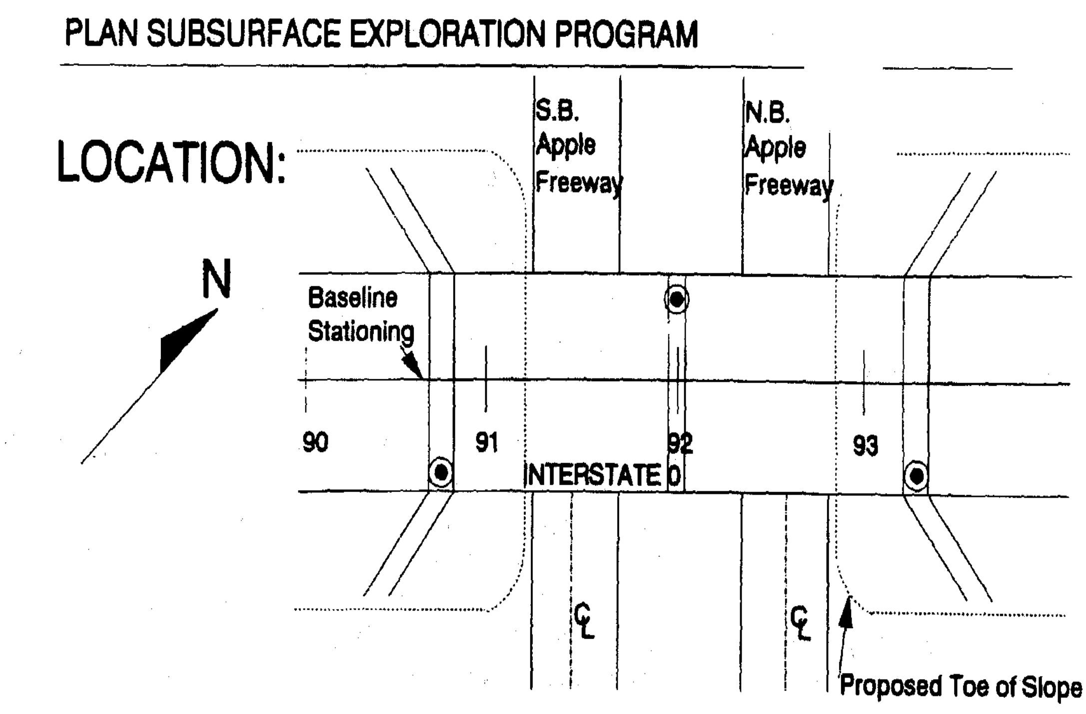
Close this session with a summary of the results of the Apple Freeway design. Note that we will provide this summary at the end of every Apple Freeway section to track the progress of the design.

Instructor should promote the NHI Subsurface Investigations course at this point.

SOILS AND FOUNDATIONS WORKSHOP

Layout of Subsurface Exploration Program

GIVEN: Soil map showed structure to be located in a delta landform. Field inspection showed wet area with cattails in vicinity of East abutment.



SOILS AND FOUNDATIONS WORKSHOP

Layout of Subsurface Exploration Program (cont'd)

TYPE: ***Disturbed SPT sample boring Hand Auger holes in wet area within East approach fill limits***

DEPTH: ***SPT holes to depth where N average equals 20 for 20' depth or 10' into bedrock whichever depth is less.***

SAMPLING: ***Pier footing: Continuous SPT samples to depth of 15', Then 5' Intervals. East and West abutments: Disturbed SPT every 5'.***

REMARKS: ***Since area a delta landform, granular deposits overlying clay may be encountered. If so, an undisturbed drill hole (UDH) will be required. The location, depth, and sampling details will be selected based on the results of the three SPT borings. Notify the drillers of possibility of UDH and vane shear so necessary equipment can be taken to site. Long term water level readings should be taken in one hole.***

LESSON 3

Basic Soil Properties for Foundation Design

BASIC SOIL PROPERTIES FOR FOUNDATION DESIGN

Lesson 3

Slide 3-1

Prior to beginning the lesson, recap the site exploration

BASIC SOIL PROPERTIES FOR FOUNDATION DESIGN

1. List Main Soil Groups and Basic Engineering Uses

2. Differentiate between Identification, Description and Classification

ACTIVITIES: Soil Description
Local Lab Tour
Geo-Quiz

Slide 3-2

How would you define soil; and write the audience response on a flip chart.

Definition of Soil

Naturally occurring mineral particles which are fairly readily separated into relatively small pieces and in which the mass may contain air, water, or organic materials.

Mineral particles of the soil mass are formed from decomposition of the rock by weathering (by air, ice, wind and water) and chemical processes.

Slide 3-3

Read definition slowly.

Focus on the points that these particles are hard and do not easily deform.

Also stress the importance of area geology in determining types of soil, which may exist.

Slide 3-4

Explain how the glacier at Portage Alaska creates soil from rock. First point out the valley glacial in the upper left and describe how the ice mass is moving downward and scouring rock from the valley wall. Then point out the material is carried into the plain by the ice and joins other valley glaciers. The soil material (shown in this picture by the dark strips in the ice) is carried to the glacier terminus where the ice melts and the soil is deposited.

Slide 3-5

Explain transported versus residual soil deposits.

Slide 3-6

Stress that laws of soil mechanics do not apply to manmade materials such as dumps and that special treatment must be considered for such situations.

Emphasize that we will only deal with simple soils in this class.

Main Soil Groups

- ***Granular Soils***
  - ***Sands and Gravels***
- ***Fine-Grained Soils***
  - ***Silts and Clays***
- ***Organic Soils***
  - ***Organic Silts and Clays, Peats, Mucks***

Slide 3-7

Introduce the soil groups which will be discussed in this lesson.

Granular Soils

Sands and Gravels

Slide 3-8

Introduce granular soils. Mention that we are starting with the most useful soil group.

Slide 3-9

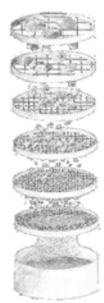
Ask how you would know from the picture that these are granular soils. The answer is that we can discern individual particle sizes with unaided eye.

Identify by Grain Size

Slide 3-10

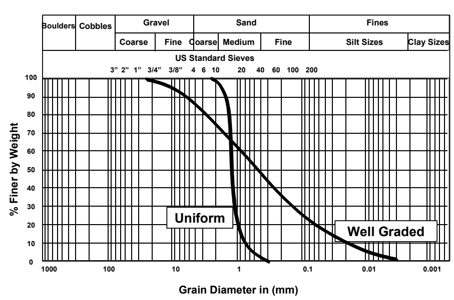
Granular soil types are identified by their grain size. Soil classification systems define the range of grain sizes for both gravel and sand particles. The smallest sand particle is just within the range of vision for the average person.

Gradation Test



Slide 3-11

Describe gradation test process and how each sieve size has standard openings in the mesh. Mention that the distribution of grain sizes in a soil sample affects the engineering properties of the mass.



Slide 3-12

Explain how gradation test results are shown and interpreted. Only discuss properties of long graded and uniform graded. Name some engineering uses for the well-graded and uniform graded soils shown in the gradation plot. Focus particularly on density and drainage properties.

Engineering Properties of Granular Soils

- ***Excellent Foundation Material***
- ***The Best Embankment Material***
- ***The Best Backfill Material***
- ***Possibly Susceptible to Vibratory Forces***
- ***Dewatering is Quite Difficult***
- ***Not Frost Susceptible if Free Draining***

Slide 3-13

Discuss engineering properties.

Fine-Grained Soils

Soil Mineral Types Control Behavior of Silts and Clays More Than Grain Size

Slide 3-14

Introduce fine grained soils. Mentioned that these particle sizes of silt and clay cannot be seen by the unaided eye. The behavior of a mass of such microscopic particles will influenced by particle attraction, adhesion, and the ability of the parent mineral to attract water. The smaller the particle size the greater the influence of the mineral type.

Cohesive Soils (Clays)

Strength Largely Derived From Cohesion

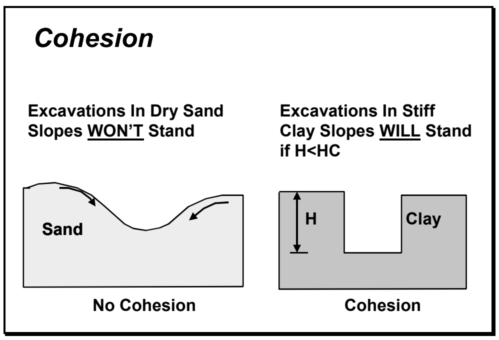
Slide 3-15

Describe cohesive bonding of microscopic soil mineral particles.

Slide 3-16

How would you know that this is a clay soil?

Show clay failure. Note how clay stands vertically due to cohesion.



Slide 3-17

Contrast clay and sand properties.

Cohesive Soils (Clays)

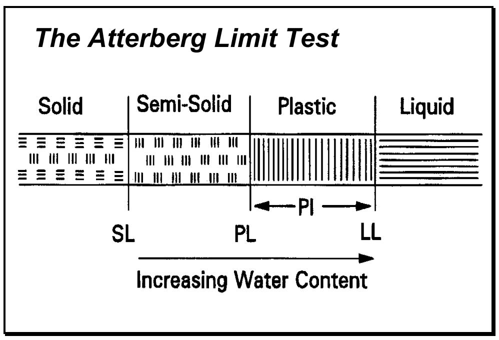
Identify by Plasticity

Slide 3-18

Identification of clay soils is done by observing the plastic behavior of the soil mass when manipulated. The relative degree to which a soil can be molded reflects the degree of plasticity of the soil mass.

Slide 3-19

Explain that plasticity is easier to show than describe. Note this sample was cut and stretched without cracking or rupture.



Slide 3-20

The physical state of a soil can vary between a solid and a liquid depending on the amount of water the sample contains. The plastic state of a soil is of most interest to the geotechnical engineer as the degree of plasticity has profound effects on the strength and consolidation characteristics of the soil. Plasticity can be easily determined in the lab by a test called the Atterberg limit test. This test will be discussed further in the lab session.

Engineering Properties of Cohesive Soils

- ***Often Possess Low Shear Strength***
- ***Plastic and Compressible***
- ***Shear Strength Reduced by Wetting or Disturbance***

Slide 3-21

List engineering properties of clay. Provide comments on the use of this soil type by the highway agency.

Engineering Properties of Cohesive Soils (Cont'd)

- ***Shrink- Swell Potential***
- ***Poor Material for Backfill or Embankments***
- ***Practically Impervious***
- ***Clay Slopes Prone to Landslides***

Slide 3-22

Continued

Silts

Similar to Clays but Exhibit No Cohesion

Slide 3-23

Introduce silts. Mention that the average silt particle size is much larger than a clay particle. Therefore silt particle behavior is less affected by particle attraction and less water thickness can be bonded by the particles.

Slide 3-24

Show how silts are sensitive to vibration; particularly when the water table is near.

Differences Between Silts and Clays

- ***Air-Dried Strength***
- ***Appearance When Shaken***
- ***Roll into Thin Threads***

Slide 3-25

Show practical ways to differentiate the behavior of silt from clay. Mention that the “shaking” test will be used in the lab exercise to identify silt behavior.

Engineering Properties of Silts

- ***Relatively Low Shear Strength***
- ***High Capillarity and Frost Susceptibility***
- ***Relatively Low Permeability***

Slide 3-26

List engineering properties of silt. Provide comments as to the use of this material by the highway agency.

Engineering Properties of Silts Compared to Clays

Silts Characteristically Have:

- ***Better Load Sustaining Qualities***
- ***Less Compressibility***
- ***More Permeability***
- ***Less Volume Change***

Slide 3-27

Contrast silt and clay properties

Slide 3-28

Introduce organic soils. Mention that organic materials are found in both residual and transported soils. An important point to remember is that organic material can absorb up to 10 times it's dry weight in water. A small amount of organic can radically change the properties of a soil mass.

Slide 3-29

Warn students that organics are problem soils.

Slide 3-30

Summarize the engineering properties with emphasis on corrosivity.

Slide 3-31

Funny slide. This is where organic originates.

Soil Classification and Description

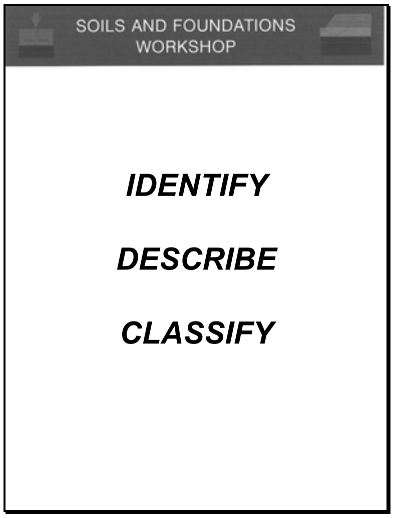
- ***Arrangement of Different Soils into Groups Having Similar Engineering Properties***
- ***Systems Most Used by Highway Agencies:***
  - *AASHTO*
  - *Unified*
  - *ASTM*

Slide 3-32

Explain concept of classification and description in relation to how geotechnical engineers communicate soil properties to each other. (It is a type of engineering language)

Slide 3-33

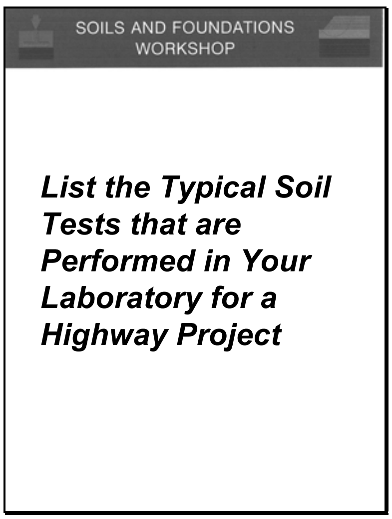
Mention that we will shortly go into the lab and get our hands dirty. Encourage the group not be afraid to handle the soils in the lab as soil should be treated as any other engineering material.



Slide 3-34

Define each term (identify …soil types; describe. estimate relative percentage of each type; classify. test each soil type) and place on flip chart. Explain that we cannot afford to classify every soil sample so we need to train people to accurately identify and describe soils.

Students are referred to the reference manual and important information highlighted in Chapter 3 and in Appendix A that contains "MUD". Instructor uses a blank overhead to illustrate the "MUD" process that will be used in the lab exercise. The focus is on primary component, secondary component, color, plasticity, and moisture condition when visualized. Put the students in the position of a new lab technician who will be trained to describe soils.



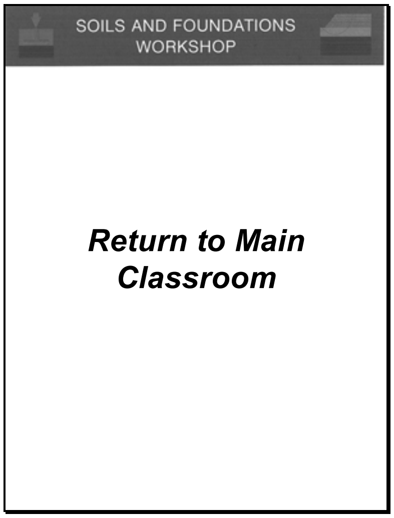
Slide 3-35

Before leaving for lab, ask student to list the lab tests that are performed in the agency lab.
Write answers on a flip chart.

Slide 3-36

Go to lab for soil description exercise and for tour of lab.

During lab exercise, ask student to describe the engineering uses of all the soils used in the exercise. Prior to beginning the lab tour encourage the students to ask questions. Be prepared to ask "icebreaker" questions to foster interaction between the lab staff and the students. Typically about 1:30 hours for exercise and tour. At the end of the exercise, acknowledge the assistance of the agency lab staff and encourage the students to take advantage of the lab services on future projects.



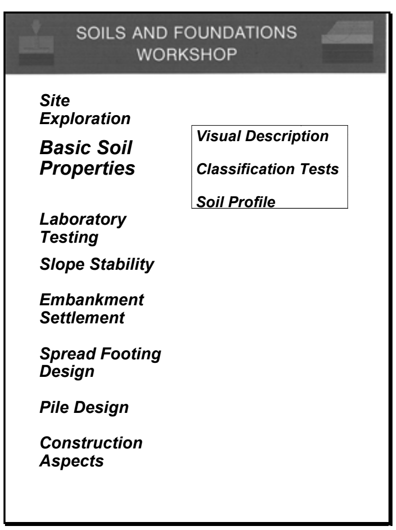
Slide 3-37

On return to classroom, ask students to add to lab test list based on what was observed in the lab visit.

Then give Geo-quiz.

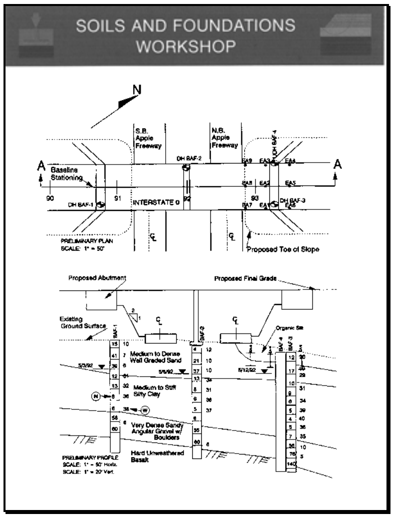
Slide 3-38

Geoquiz Slide is animated such that no answers are shown until left click is depressed sequentially.



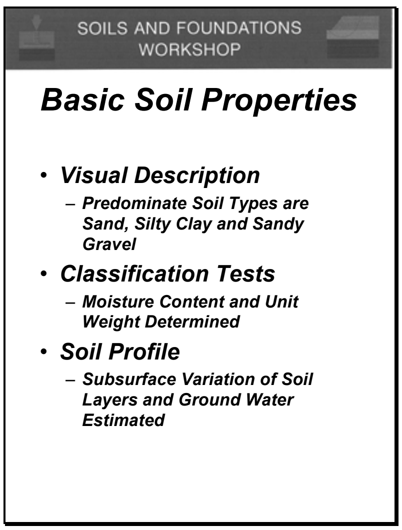
Slide 3-39

After the Geo-quiz, ask the students open the reference manual to highlight the remaining information in Chapter 3 and to begin the Apple Freeway. Show summary to build on site exploration information from previous section. Note we are still in the data collection phases of the project.



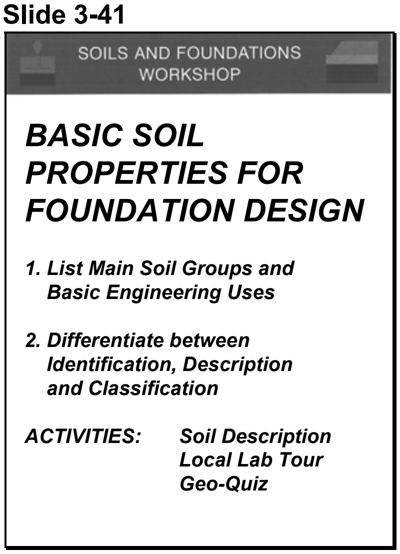
Slide 3-40

Ask group what information was used to develop the soils profile. The answer is the combined results of the terrain reconnaissance, site inspection, and soil/water data from the subsurface logs.



Slide 3-41

Summarize what was done in this segment of the Apple Freeway.



Slide 3-42

Review the initial objectives of this lesson.

LESSON 4

Laboratory Testing for Foundation Design

LABORATORY TESTING FOR FOUNDATION DESIGN

Lesson 4

Slide 4-1

Review process sheets on wall before beginning the lesson.

Note that lab testing will only be as good as the quality of the samples taken in the site exploration phase. Complement the drillers again for their dedication.

LABORATORY TESTING FOR FOUNDATION DESIGN

1. Compute and Plot Total, Effective, and Water Pressures on a P_O Diagram
2. Apply Consolidation and Shear Strength Test Results

ACTIVITY: Compute and Diagram Total & Effective Pressures

Slide 4-2

Explain objective and note that computation work will begin in this lesson.

Divide the group into teams to solve the student exercises.

Stress that teamwork is important and those who are faster should assist the others.

The instructor will put all team numbers in a hat and select one team to explain each exercise to the group.

Samples for Lab Tests

Disturbed Samples May Be Used for:
- ***Visual Classification/Description***
- ***Moisture Content***
- ***Specific Gravity***
- ***Atterberg Limits***
- ***Gradation***
- ***Compaction***

Slide 4-3

Relate previous knowledge of soil sample types to their uses in soil testing.

First for disturbed samples.

Samples For Lab Tests (Cont'd)

Undisturbed Samples Required For:

- ***Unit Weight***
- ***Consolidation***
- ***Unconfined Compression***
- ***Triaxial Compression***

Slide 4-4

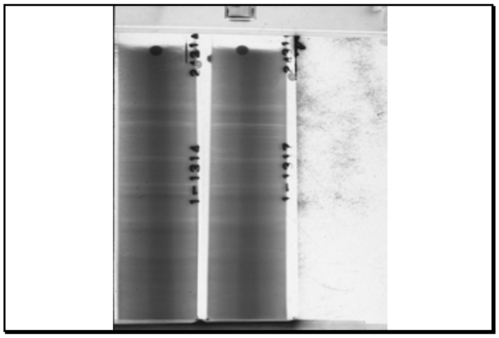
Then undisturbed samples. Point out that the internal structure of the soil sample must be preserved if test results are to be representative of conditions in the soil deposit.

Slide 4-5

State sample storage requirements. Mention that undisturbed soil samples should be stored in a moist environment to prevent changes in sample moisture content.

Slide 4-6

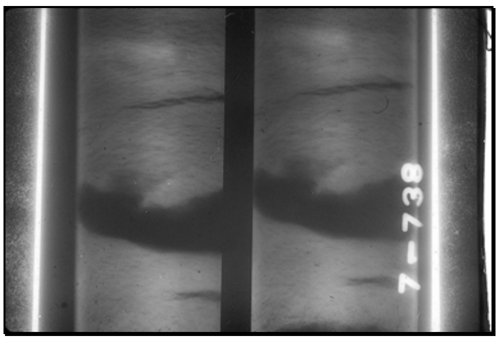
What is the problem with tube storage in the picture? Answer is that the tubes are being stored in a horizontal position rather than vertical.



Slide 4-7

Instructor will now show a series of Shelby tube samples which were X-rayed prior to opening the tube. X-raying is done to detect problems occurring in the sampling or transportation process and to observe the quality of the overall sample for selection of the lab test samples. Only a handful of agencies now use this process which costs about $15 per tube.

This tube shows a good quality sample with horizontal layers. Note soil types can be located by the shadings of color.



Slide 4-8

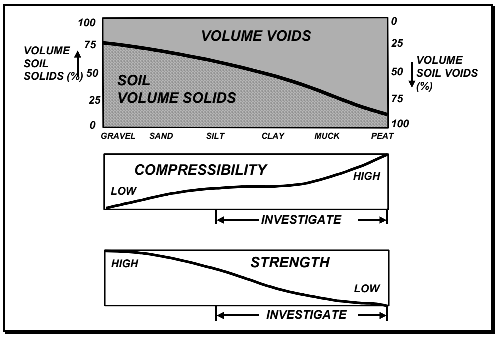
Bad sample.

What could cause the sample separation shown in the picture?

Answer is poor transportation and handling.

Slide 4-9

One method of sample extrusion; comment on other methods.



Slide 4-10

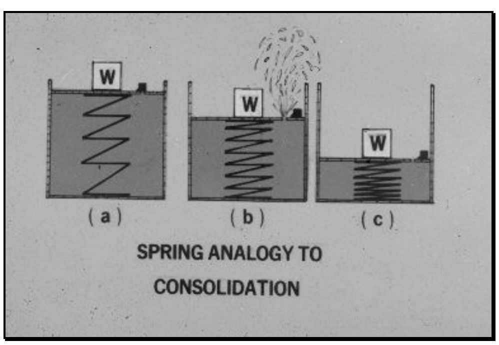
Recall the definition of soil, which involves mineral particles, water and air. Explain that the phase diagram used in this course assumes that the volume of solids represents the mineral particles and the volume of the voids is simplify understanding of basic soil properties and testing concepts.

Also note that lab testing is concentrated on soils that contain significant amounts of water. Since water has no strength, such soils tend to be weak and compressible; a problem for highway construction.

Total, Effective and Water Stresses

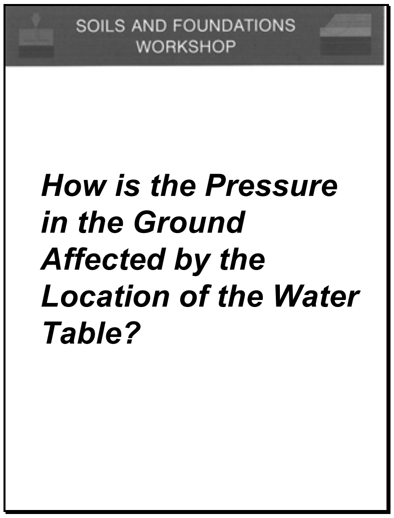
Slide 4-11

Introduce the three important stresses in the ground; total stress, effective stress, and water stress. Mention that knowledge of these parameters is needed to specify lab tests for strength and compressibility.



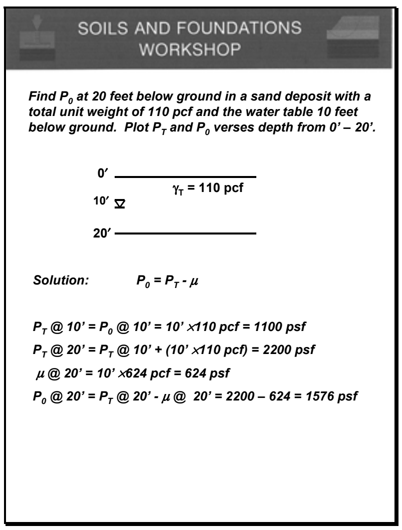
Slide 4-12

Show effective stress analogy. Explain step by step how the applied load is transferred from the water to the mineral skeleton (spring). Impress on the group that the total stress in the system is composed of stresses in the skeleton and stresses in the water. Long term support of load is done by the skeleton. Then go to the reference manual and explain the contents of the section on overburden pressure in Chapter 4. Instructor should use a blank overhead to demonstrate the computation of total stress at two depths for a hypothetical soil profile with no water table.



Slide 4-13

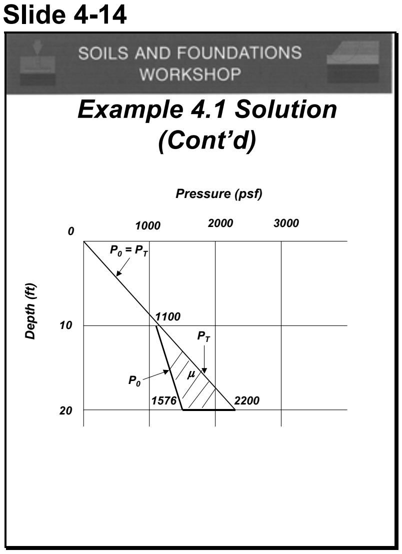
Then show overhead which asks how the position of the water table affects pressure in the ground. After receiving answers from the group, use the previous total pressure overhead to show the water pressure reduces the total pressure to an effective pressure. Write the equation for effective pressure at the top of the overhead and refer to location in the reference manual for the example problem which will be used to illustrate the concept of overburden pressure.



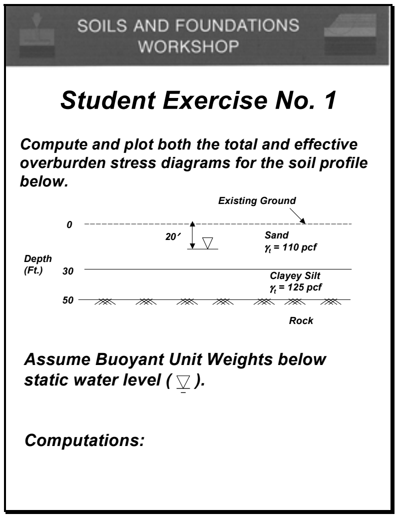
Slide 4-14

The instructor should use a blank overhead and do this example by hand. Explain Example 4.1 with emphasis on first computing total pressure at a depth, then the water pressure, then subtracting the water pressure from the total pressure to find the effective pressure. After plotting results point out the water pressure on the diagram.

Instructor then shows the student exercise overhead. After completing the explanation of what is wanted, replace the example problem overhead to assist students in solution of the student exercise.



Slide 4-15



Slide 4-16

Instructor assigns students to teams and asks all to solve the student exercise. Announce that after the students have completed the problem, one team will be selected to put the solution on a flip chart and explain the answer.

After the explanation, the instructor may ask other team members pertinent questions such as; why overburden pressure is important to know before beginning lab testing. This is the first exercise, which involves teams and computational work. The instructor must carefully monitor how the teams are interacting and insure that every student succeeds in obtaining the answer to the exercise; regardless of how long the exercise takes. Teamwork must be encouraged. Technically the exercise is a simple computation of total and effective stresses. The instructor should initially only focus on the computational process. However the students will use the concepts learned from this exercise in all future exercises, which involve ground stresses.

Please refer to the end of the lesson for this exercise.

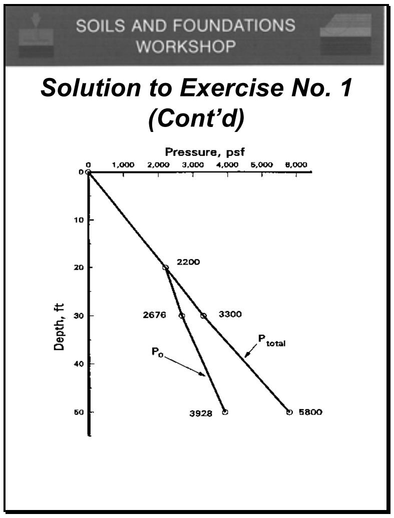
Depth Feet	Δ Layer Thick, Feet	γ_t pcf	P_{total} psf	Pore Pressure psf	P_o* psf
20	20	110	2200	0	2200
30	10	110	1100+2200 = 3300	10 x 62.4 624	2676
50	20	125	2500+3300 = 5800	30 x 62.4 1872	3928

* P_o could also be computed using γ_b below water table.

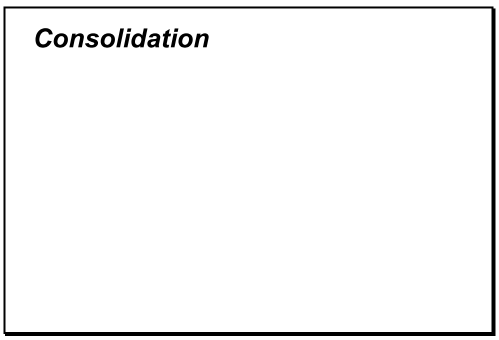
Slide 4-17

After the student explanation shown this overhead and explain any missing elements to the solution. Post the student solution on the wall after the exercise is complete.

Please refer to the end of the Participant Workbook for the solution to this exercise.



Slide 4-18

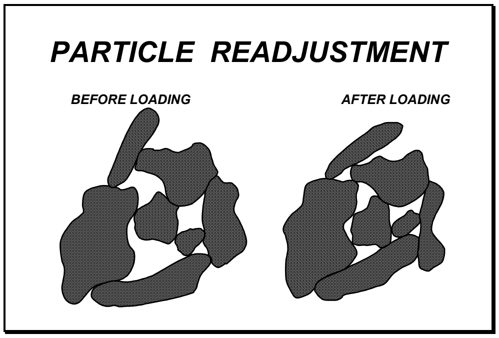


Slide 4-19

Introduce consolidation. Mention that consolidation testing is used to predict settlement. Also state that the consolidation process affects the strength of soil deposits.

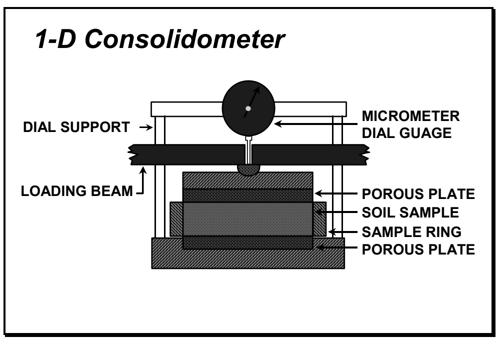
Slide 4-20

Case history of consolidation. Highway embankment built over soft ground. Fill settled over one foot. Note that a severe bump exists over the drainage pipes which ere placed on piles. The different settlement was so great that water ponds on the highway and cannot reach the catch basin. Poor communication in design of fill and design of drainage.



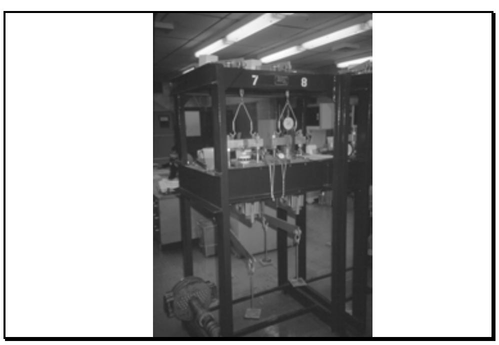
Slide 4-21

Recall that mineral particles are hard and reorient when loaded rather than compressing. Explain volume of solids, volume of voids and voids ratio. Note that after loading, the volume of the voids (and therefore the voids ratio) are reduced.



Slide 4-22

Explain test apparatus concept. A representative soil sample is placed in the device. A prescribed standard sequence of loads are applied to the sample. Deflection of the sample is measured with time after application of each load.

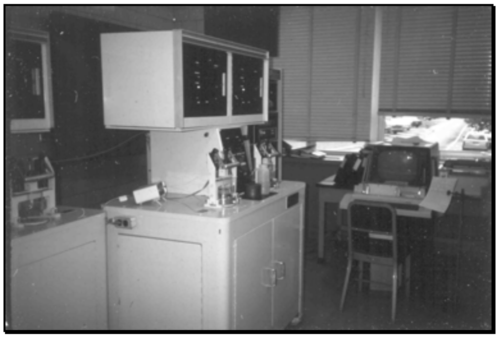


Slide 4-23

Instructor may adjust the time spent on the consolidation equipment in the section depending on the extent of coverage in the lab tour.

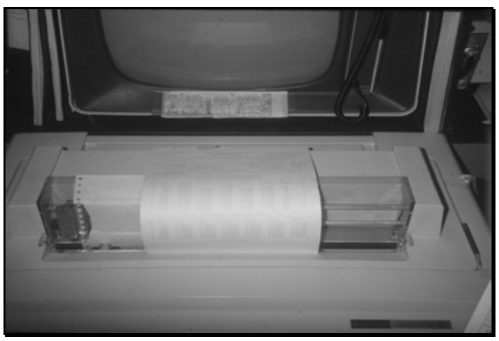
A typical basic manual apparatus is shown here. Note the lever arm and weights which are used to apply high pressure to the small soil sample. Typical maximum test loads are in the order of 32 tons per square foot.

Mention that even this basic equipment can be modified for automated operation for a modest cost.



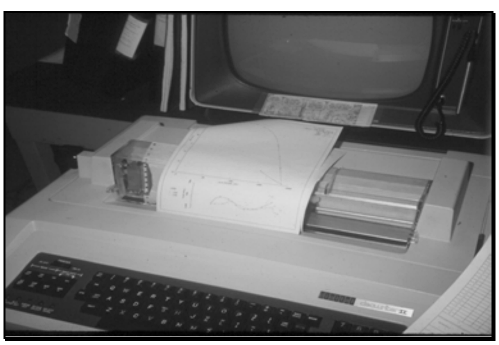
Slide 4-24

Show computerized system. Mention that these systems substantially reduce the staff time devoted to reading dials and computing test results.



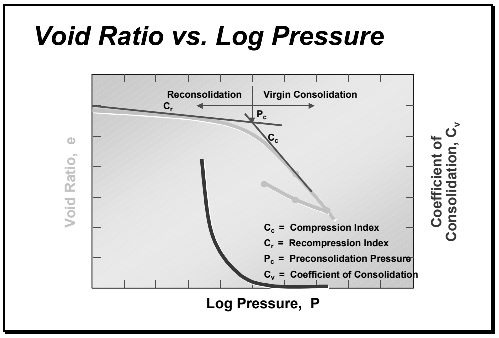
Slide 4-25

Show computerized computations.



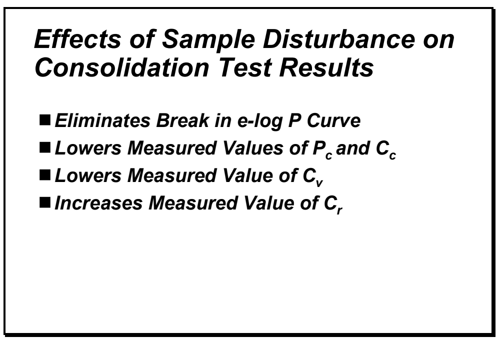
Slide 4-26

Show computerized plotting feature.



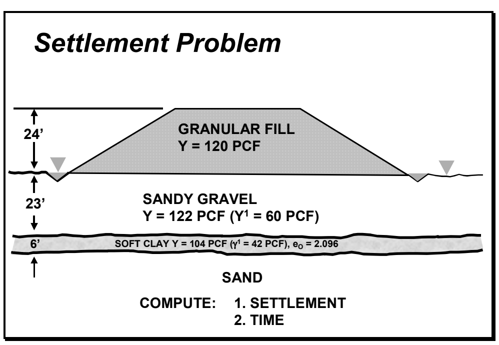
Slide 4-27

Explain the e-log P plot and how to extract pertinent information. Focus particularly on compression and recompression indices and the preconsolidation pressure. Mention that other plots are used to find the coefficient of consolidation and estimate the drainage rate. Refer to the position of the C_v – log P curve and how drainage rate slows with increasing load. Then go to the reference manual and point out the plots in Chapter 4 and the accompanying description of each item.



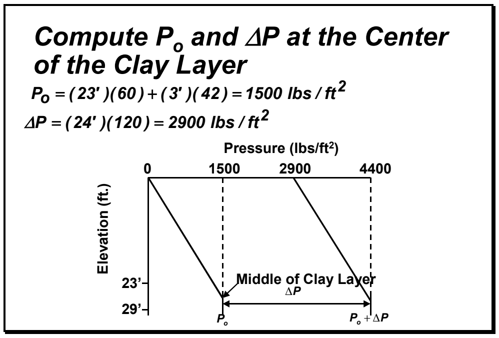
Slide 4-28

Review the importance of the drillers properly handling and transporting the samples.



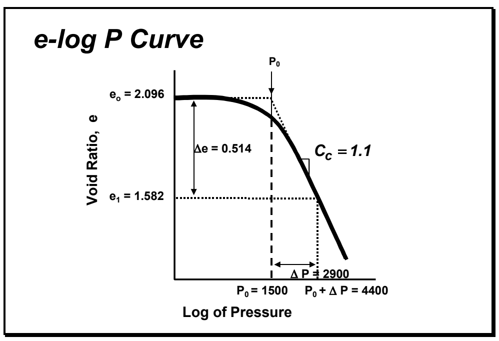
Slide 4-29

Relate the test results to a practical problem solution. State the problem of finding the embankment settlement. Ask the group what would be the first step to find the settlement? The answer is to take undisturbed samples in the clay layer then outline the process to predict settlement from the results of a consolidation test, i.e., find P_o at center of clay layer, find change in pressure at center of clay layer due to embankment load, use consolidation test to find the change in voids ratio between the P_o and P_f pressures.



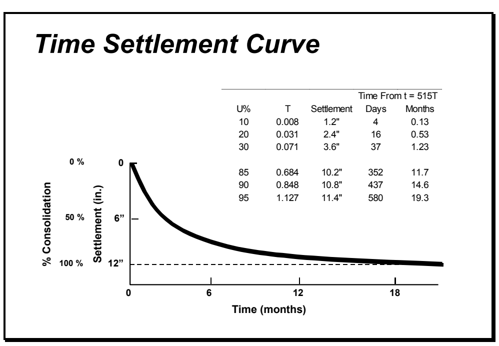
Slide 4-30

Explain settlement computation process. First is the computation of P_o and P_f.



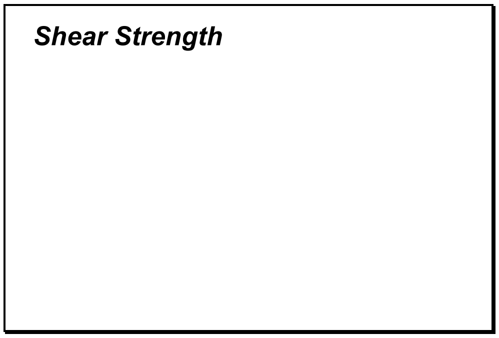
Slide 4-31

Explain how test data used in computation. Note that the e-log P plot is entered with P_o and P_f pressure to find the change in voids ratio, e, due to the applied load. This change is directly related to the amount of settlement.



Slide 4-32

Demonstrate how the results from a small sample can be used to make predictions about embankment behavior. What soil types are suited for consolidation testing? The answer is fine-grained and organic.



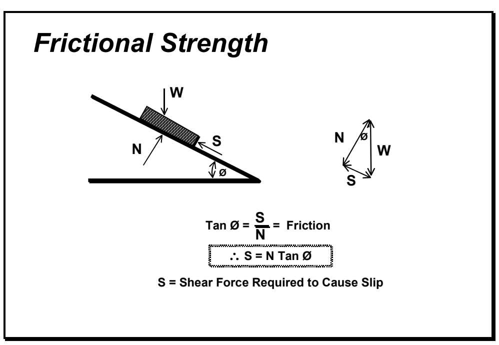
Slide 4-33

Introduce shear strength.

How does consolidation affect shear strength? The answer is the increase in contact between particles increase the shear strength.

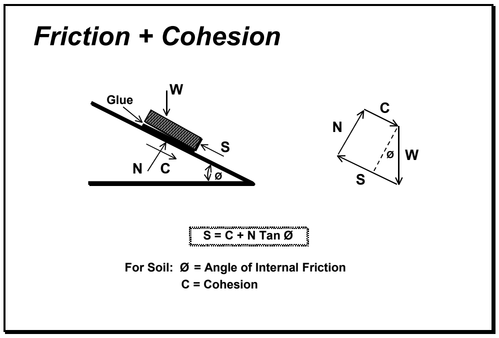
Slide 4-34

Case history of low shear strength causing slope failure. Trucks were dumping waste clay at the top of this marginally stable slope. When the weight of the clay and the trucks exceeded the shear strength of the clay, the slope failed. The trucks and their drivers rode down 60' on the failure mass. Funny comment; the drivers now understand shear strength.



Slide 4-35

Sliding block-friction analogy. Stress equation. Expand the concept to explain that friction is composed of both surface roughness and particle interlock effects. Stress equation shows that frictional shear strength increases as the pressure between the particles increases.



Slide 4-36

Sliding block with glue is the analogy for combined friction/cohesion forces between soil particles. Stress equation for the strength of any soil includes a contribution due to friction and a contribution due to cohesion. This is a basic concept of soil mechanics.

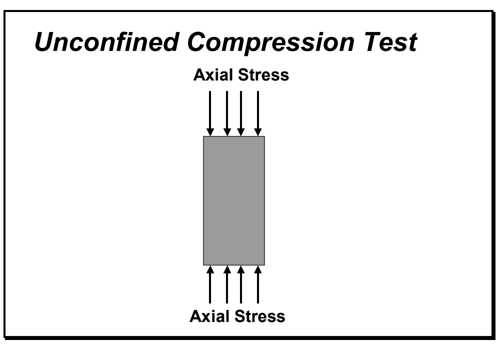
Typical Methods of Shear Strength Testing

- ***Lab Tests***
  - *Unconfined Compression Test*
  - *UU Triaxial Compression Test*
  - *CU Triaxial Compression Test*
  - *CD Triaxial Compression Test*
  - *Direct Shear Test*
- ***Field Tests***
  - *Vane Shear*

Slide 4-37

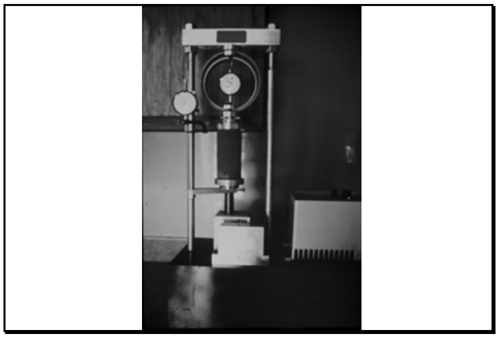
List types of strength testing. Ask students what acronyms mean. The answer is the consolidation state prior to shear and the drainage during shear.

Instructor may adjust the time spent on the shear strength slides based on what was covered in the lab tour. In general the knowledge conveyed to the group is a description of the basic concept of each test including the apparatus, typical results format, and an evaluation of the test type.



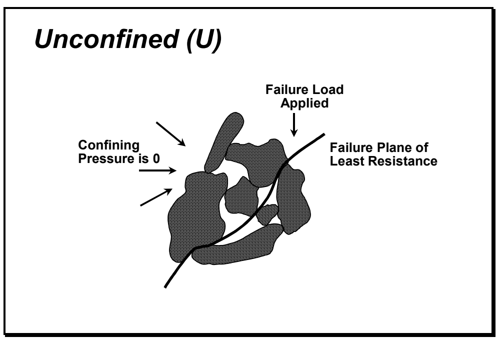
Slide 4-38

The unconfined test is performed on a sample without the application of confining pressure.



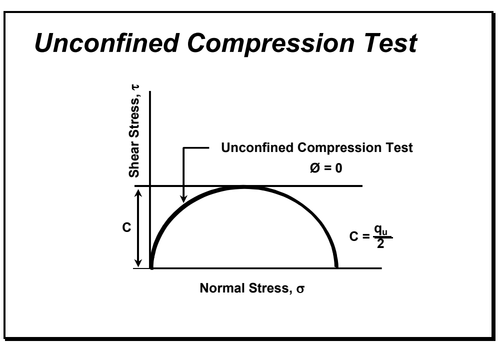
Slide 4-39

The apparatus for this test is found in most labs. The equipment applies an axial load at a defined rate while deflection measurements are taken.



Slide 4-40

Describe how, at failure, a shear plane develops between the particles. Impress on the group that the particle do not shear and the strength of the samples is based on the bond between particles.



Slide 4-41

Note that the results of an unconfined test are commonly presented to the designer in the form of a Mohr diagram with the circle originating at the zero axis. The test result is the cohesion. Ask students why a frictional strength is not reported. Answer is N=0. Therefore friction is 0.

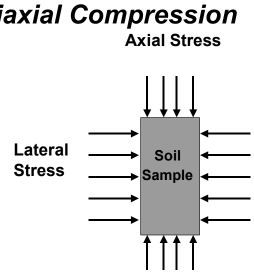
Unconfined Compression Test

- ***Quick, Economical Test to Approximate the the Shear Strength of Cohesive Soils at Shallow Depths***
- ***Poor Reliability for Samples Extracted From Increasing Depths***
- ***Should Only be Performed on Samples Extruded Directly from the Tube and Tested at Full Diameter***

Slide 4-42

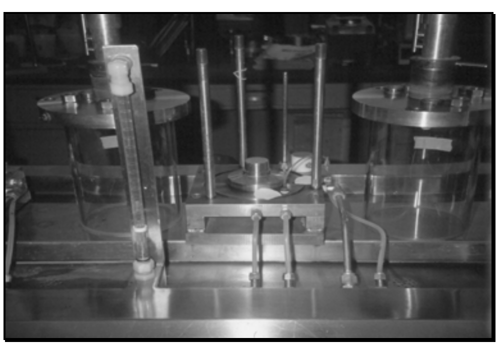
Evaluate the test. Explain that test results can be significantly affected by swelling of the sample after removal from the tube. The release of confining ground stresses affects the soil structure and the strength.

Triaxial Compression



Slide 4-43

Note that the triaxial test involves application of confining pressures to the soil sample to model actual stresses in the ground. The test has several variations that involve the pre-shear consolidation of the sample and the drainage of the sample during shear.

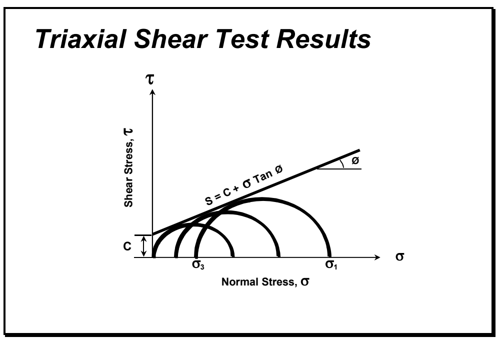


Slide 4-44

The triaxial apparatus is designed to permit water to drain from the top and bottom of the sample. Note the use of filter paper and the function of the burette that monitors sample consolidation.

Slide 4-45

In the sample set-up, note the sample is encased in a membrane. The test cylinder is filled with a fluid (commonly glycerin) that distributes the confining pressure over the surface of the sample.



Slide 4-46

The triaxial results received by the designer are commonly shown in the form of a Mohr diagram with circles originating at the confining pressures selected for the test samples. An envelope may be drawn tangent to the circles to determine friction angle and cohesion intercept. Mention σ_3 is the confining pressure in the triaxial test

Unconsolidated Undrained (UU) Triaxial Compression Test

- ***Quick and Relatively Economical***
- ***Reliability Depends on Sample Retaining In-situ Characteristics***
- ***Tests Should Only be Performed on Samples Extruded Directly from the Tube and Tested at Full Diameter***
- ***Useful for Embankment Stability Problems***

Slide 4-47

The results of UU tests represent the in-place strength of the soil deposit prior to any external consolidation. These results are commonly used in embankment stability analyses as the results conservatively do not include strength gain due to consolidation.

Consolidated Undrained (CU) Triaxial Compression Test

- ***Quick Test on Multiple Samples to Determine the Shear Strength for a Range of Consolidation Pressures***
- ***Effective Stress Parameters can be Estimated if Pore Pressure Measurements are Taken***
- ***Results Useful for Staged Construction Problems***

Slide 4-48

Consolidation triaxial tests are commonly performed on 3 separate sample taken from the same depth but confined under different pressures. These pressures represent the range of expected stresses to be applied to the ground during construction. CU test results provide the relationship between strength and consolidation pressure. Engineers rely on such results to predict strength increases under embankment loads when constructing over soft ground.

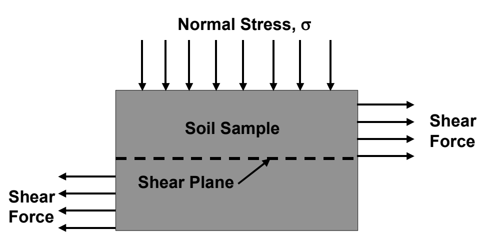
Consolidated Drained (CD) Triaxial Compression Test

- ***Time Consuming Test to Find Effective Stress Strength Properties for a Range of Consolidation Pressures***
- ***Multiple Samples Required***
- ***Results Useful for Cut Slope Stability Problems***

Slide 4-49

Also performed on multiple samples. CD test equipment is designed to accommodate very low strain rates. Such strain rates are needed to prevent the development of excess pore pressures in the sample during testing. The test results are represented as a drained friction angle and a small cohesion value that is commonly ignored in design analyses.

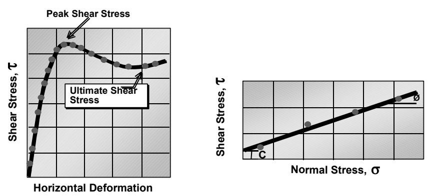
Direct Shear Test



Slide 4-50

The direct shear test is generally performed on granular soils that are not affected by internal drainage during shear. The granular soil is placed in a segmented shear box. A normal force is applied to the sample and the segments pulled apart to measure the failure shear force across the pre-determined plan. Since normal force and failure stress are known, the friction angle can be computed.

Direct Shear Test Typical Results



Slide 4-51

Direct Shear Test

- ***Normally Performed on Granular Soils to Find Friction Angle***
- ***Particle Sizes Limited by Shear Box Size***
- ***Residual Friction Angle Can be Determined at Large Strain Values***
- ***Cohesive Soils Require Special Equipment***

Slide 4-52

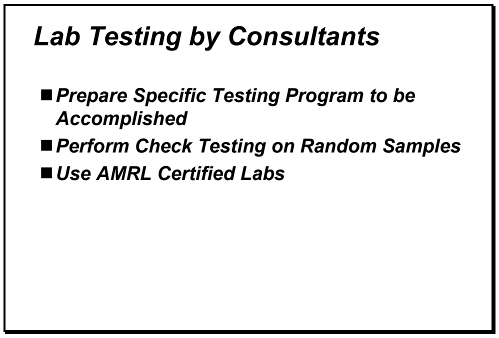
Direct shear test equipment is low cost and can handle granular soil particle sizes up to 0.1”. The results of the test are generally reported as a friction angle. More sophisticated direct shear equipment is available to perform tests on larger particle sizes or to test interface friction with non-soil material or to test cohesive soils.

Lab Testing Guidelines

- ***Visual Descriptions for All Soil Samples***
- ***Moisture Content on all Fine-Grained Samples***
- ***Classification Tests on Representative Samples***
- ***Shear Strength and Consolidation Tests in Cohesive Deposits to Determine Property Variation with Depth***

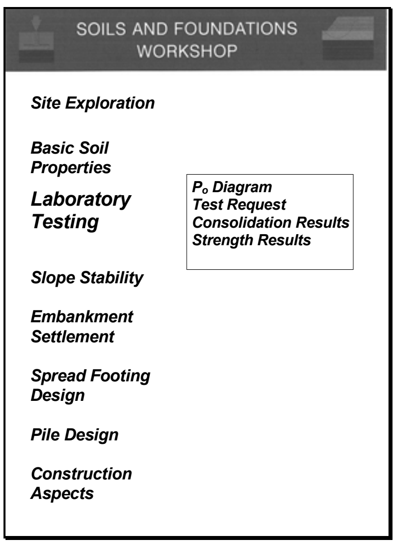
Slide 4-53

Review basic minimum lab guidelines.



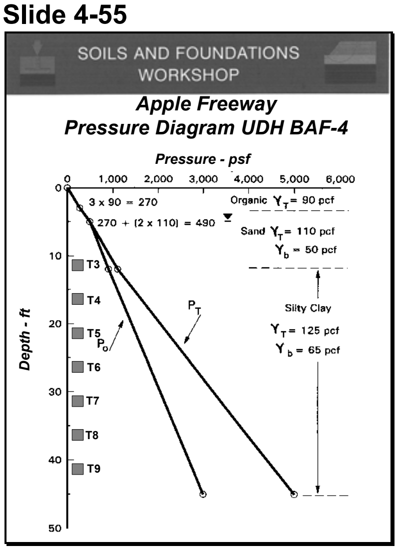
Slide 4-54

Stress the need for standard lab procedures to obtain reliable test results.



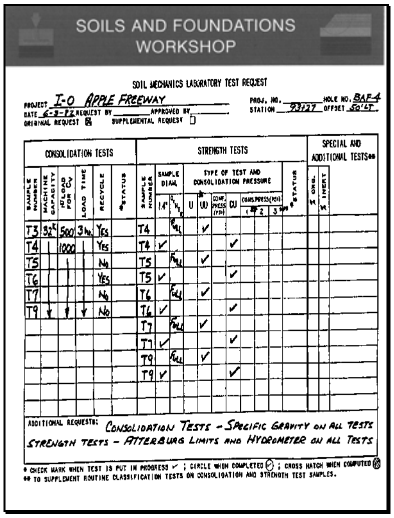
Slide 4-55

Build on the data collection for the Apple Freeway project.



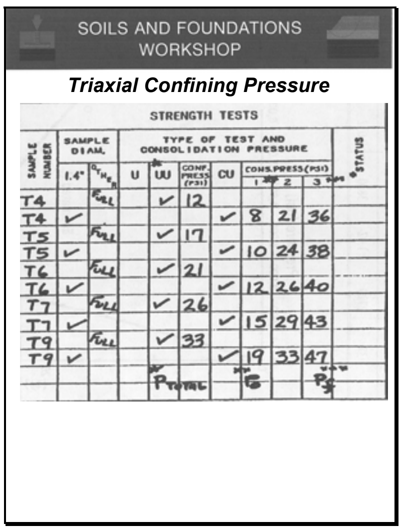
Slide 4-56

Show Po diagram for Apple Freeway. Note that the tube depths have been plotted at the depths where extracted from UDH-BAF-4. Ask students to use P_o diagram and fill in a few pressures for strength tests at the depths on the following test request as requested by the instructor.



Slide 4-57

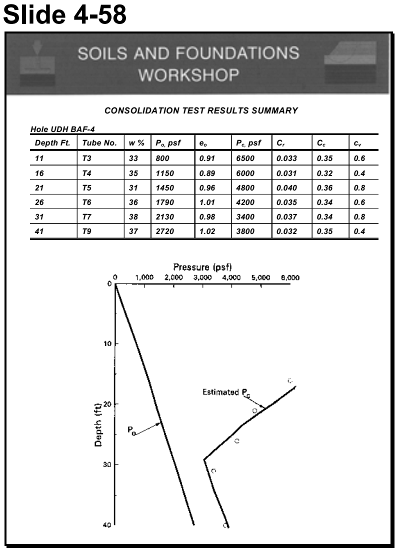
Explain how total pressure is used for UU tests and effective pressure is used for CU tests. Make sure students convert the pressures to psi which is used for gage pressure.



SAMPLE NUMBER	SAMPLE DIAM. 1.4"	SAMPLE DIAM. OTHER	U	UU	CONF. PRESS (PSI)	CU	CONS. PRESS (PSI) 1	2	3	STATUS
T4		FULL		✓	12					
T4	✓					✓	8	21	36	
T5		FULL		✓	17					
T5	✓					✓	10	24	38	
T6		FULL		✓	21					
T6	✓					✓	12	26	40	
T7		FULL		✓	26					
T7	✓					✓	15	29	43	
T9		FULL		✓	33					
T9	✓					✓	19	33	47	
				P TOTAL			σ̄		Pₛ	

Slide 4-58

Explain how total pressure is used for UU tests and effective pressure is used for CU tests. Make sure students convert the pressures to psi which is used for gage pressure. At completion of the exercise, refer student to the answer which is located in the reference manual, page 4-21 then ask how the student would summarize test results received from the lab? Instructor then shows lab summary for consolidation and shear strength and Apple Freeway summary.



Depth Ft.	Tube No.	w %	P_o, psf	e_o	P_c, psf	C_r	C_c	c_v
11	T3	33	800	0.91	6500	0.033	0.35	0.6
16	T4	35	1150	0.89	6000	0.031	0.32	0.4
21	T5	31	1450	0.96	4800	0.040	0.36	0.8
26	T6	36	1790	1.01	4200	0.035	0.34	0.6
31	T7	38	2130	0.98	3400	0.037	0.34	0.8
41	T9	37	2720	1.02	3800	0.032	0.35	0.4

Slide 4-59

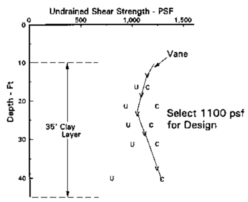
When showing solutions, stress the plotting of the P_c and SS values with depth. Impress on students that all test values should not simply be averaged to find the mean value.

SOILS AND FOUNDATIONS WORKSHOP

SHEAR STRENGTH TEST RESULTS SUMMARY

Hole UDH BAF-4

Depth Ft.	Tube No.	w %	Undrained Strength – psf U_u (U)	C_u @ P_o (C)	Vane (V) Undisturbed	Vane (V) Remolded
13		34			1150	550
16	T4	34	1050	1150		
18		36			1100	600
21	T5	35	950	1250		
23		38			1050	500
26	T6	39	975	1200		
28		37			1125	550
31	T7	40	1000	1250		
37		35			1250	600
41	T9	38	800	1300		



Slide 4-60

When showing solutions, stress the plotting of the P_c and SS values with depth. Impress on students that all test values should not simply be averaged to find the mean value.

SOILS AND FOUNDATIONS WORKSHOP

Laboratory Testing

P_0 Diagram

Increase of pressure in the soil with depth.

Test Request

Test pressures represent range of increase due to the embankment.

Consolidation Results

Compressibility, precompression and drainage rate of clay deposit.

Strength Results

Cohesion and increase of shear strength with confining pressure found.

Slide 4-61

Summarize Apple Freeway progress

Instructor promotes new FHWA GEC #5 on soil and rock properties.

SOILS AND FOUNDATIONS WORKSHOP

Laboratory Testing for Foundation Design

1. ***Compute and Plot Total, Effective, and Water Pressure on a P_o Diagram***
2. ***Apply Consolidation and Shear Strength Results***

Activity: Compute and Diagram Total and Effective Pressures

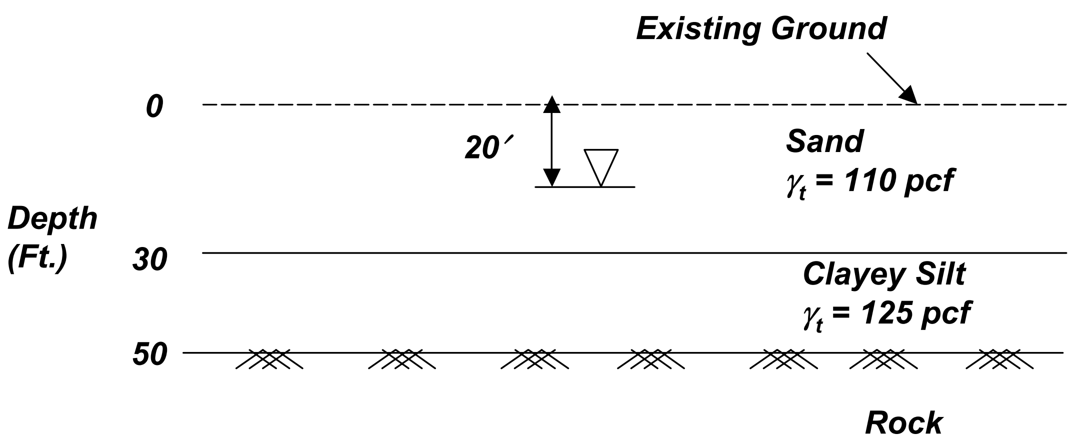
Slide 4-61

Repeat Objectives

SOILS AND FOUNDATIONS
WORKSHOP

Student Exercise No. 1

Compute and plot both the total and effective overburden stress diagrams for the soil profile below.



Assume Buoyant Unit Weights below static water level (▽).

Computations:

SOILS AND FOUNDATIONS WORKSHOP

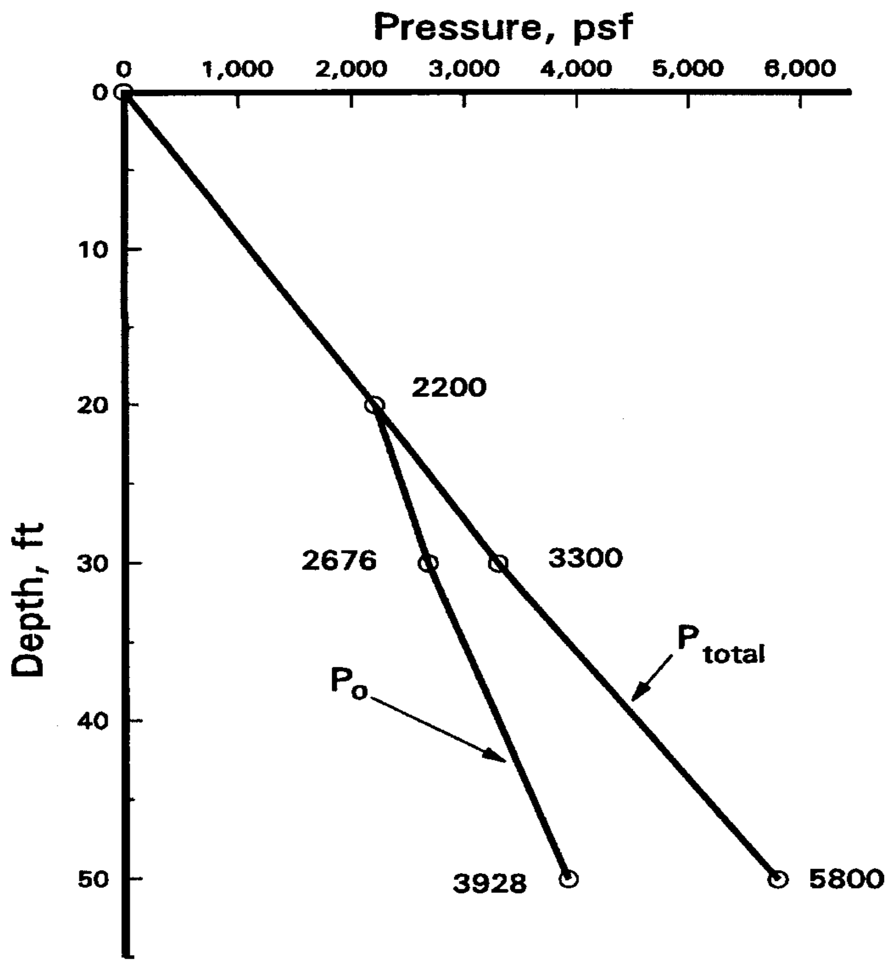
Solution to Exercise No. 1

Depth Feet	Δ Layer Thick, Feet	γ_t pcf	P_{total} psf	Pore Pressure psf	P_o* psf
20	20	110	2200	0	2200
30	10	110	1100+2200 = 3300	10 x 62.4 624	2676
50	20	125	2500+3300 = 5800	30 x 62.4 1872	3928

***** P_o could also be computed using γ_b below water table.**

SOILS AND FOUNDATIONS WORKSHOP

Solution to Exercise No. 1 (Cont'd)



LESSON 5

TOPIC 1

Slope Stability

SLOPE STABILITY

Lesson 5 - Topic 1

Slide 5-1-1

Instructor should note that the previous lessons represent the data-gathering phase of the geotechnical process. The remaining lessons will build on this information to develop design information for a project. Stress again that the reliability of any design work will depend on the quality and quantity of subsurface data.

The first design lesson is slope stability. This lesson will be subdivided in two sections; embankment stability and cut slopes.

SLOPE STABILITY

1. *Compute Resisting & Driving Forces*
2. *Explain Effects of Water Pressure on Frictional Resistance*

ACTIVITIES: Circular Arc Analysis
Sliding Block Analysis

Slide 5-1-2

Explain objectives. Mention that hands on student exercises will be used to develop computation skills in stability analysis.

Embankments:
Major Design Considerations

- *Stability*
- *Settlement*
- *Effects on the Structure*

Slide 5-1-3

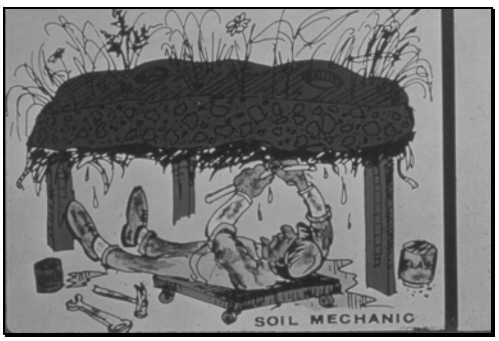
Begin the embankment stability session with a review of the major considerations for embankment design.

Embankment Stability Problem Soils

- ***Low Strength Clays***
- ***Low Strength Silts***
- ***Peats***
- ***Organic Silts and Organic Clays***
- ***Thin, Weak Seams (Clay, Silt, Sand)***

Slide 5-1-4

Introduce stability problem soils. Relate back to what was observed in the lab exercise and why lab testing is usually concentrated on these soils.



Slide 5-1-5

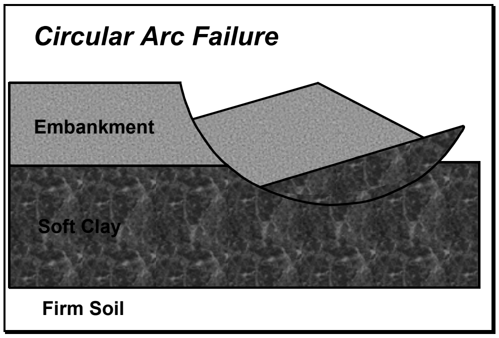
Funny slide to show that we work below ground.

Major Stability Problems

Circular and Sliding Block Failures

Slide 5-1-6

Introduce circular and sliding block failure types. Mention that these are the most common failure modes for embankments.

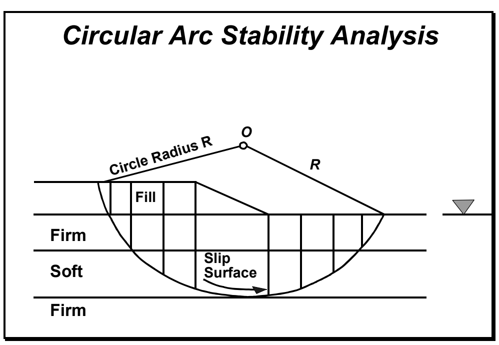


Slide 5-1-7

Describe circular failure. Note that the failed mass rotates in a circular shape with the top dropping and the toe rising. Ask what causes the failed mass to stop rotating?

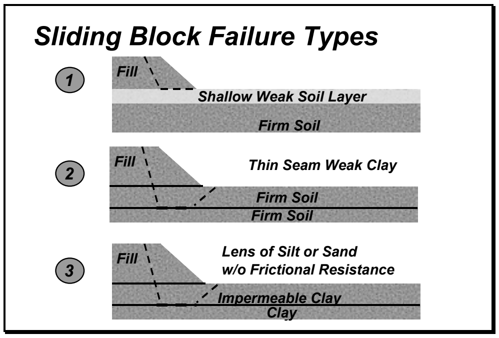
Slide 5-1-8

Show case history. Note the head scarp to the left and the relative height compared to the size of the man standing below the scarp. Note the mud wave at the toe and the relative scale compared to the man near the toe.



Slide 5-1-9

Spend a few minutes on this slide to show the mechanics of a slip circle analysis. Mention how the circular mass is subdivided into a series of slices. Note that certain rules govern where the slices are placed; breaks in ground line, water table, or subsurface layers. Hand methods of analysis commonly require 10-15 slices. Computer methods generally select the number of slices as a function of circle geometry.

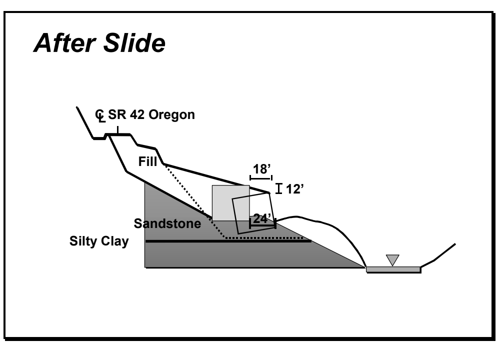


Slide 5-1-10

Describe the three common conditions for a sliding block failure. Note that the presence of water or increased water pressure is frequently a contributing factor to sliding block problems.

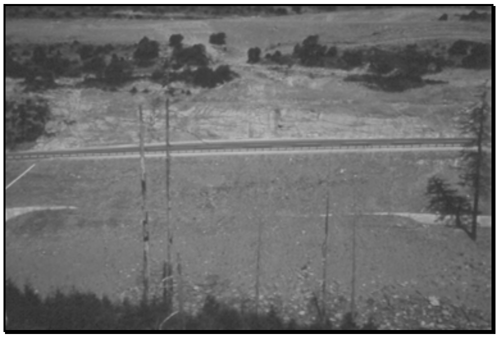
Slide 5-1-11

Show sliding block case history for failure of Reinforced Earth wall at Coos Bay Oregon. This wall was built to prevent a sliver fill section for a road widening from spilling into a river. The failure occurred during placement of a fill slope above the top of the wall. Also note how well the reinforced system withstood the failure movement. The wall actually prevented the failed mass from sliding into the river.



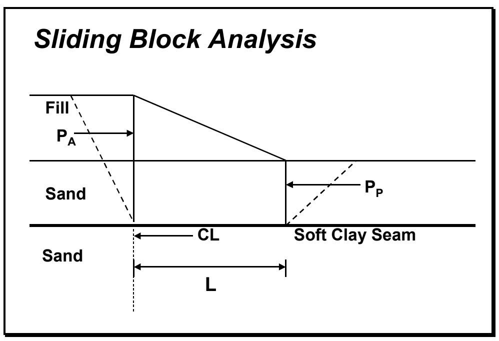
Slide 5-1-12

Describe the mechanism that caused the sliding block failure and the amount of movement associated with the failure. The cause of the failure was a thin seam of silty clay that was not found during the initial subsurface investigation.



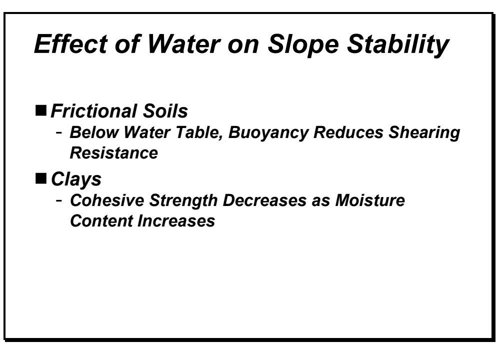
Slide 5-1-13

The remedy for the failure was to place a buttress in front of the failed section of the wall. (Funny line to use is that we employed a method commonly associated with doctors; we buried the wall.) This buttress only resulted in a minor encroachment into the river as the length of the failed section was short.



Slide 5-1-14

Describe mechanics of a sliding block failure. Point to the active wedge, central block, and passive wedge. Note that factor of safety for stability analysis is defined as resisting forces over driving forces.



Slide 5-1-15

Emphasize the water effect on various soil types.

Effect of Water on Slope Stability (Cont'd)

- ***Fills on Clays and Silts***
  - *Soil Consolidates as Water is Squeezed Out - Factor of Safety Increases With Time*
- ***Cuts in Clay***
  - *Soil Absorbs Water When Overburden Pressure Removed - Factor of Safety Decreases With Time*

Slide 5-1-16

Emphasize the water effect on various soil types.

Effect of Water on Slope Stability (Cont'd)

- ***Shales, Claystones, Siltstones, Etc.***
  - *Weak Rock Materials "Slake" When Exposed to Water - Embankments Undergo Internal Settlement or Failure*

Slide 5-1-17

Emphasize the water effect on various soil types.

Embankments: Recommended Safety Factors

$$\text{Safety Factor} = \frac{\text{Resisting}}{\text{Driving}}$$

- ***End Slope Conditions***
  - *Minimum Safety Factor = 1.30*
- ***Side Slope Conditions***
  - *Minimum Safety Factor = 1.25*

Slide 5-1-18

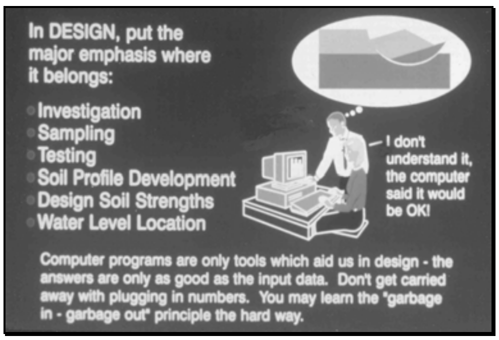
State the recommend safety factors for both end and side slopes. Ask why the safety factor is higher for end slopes?

Basis for Selection of Design Safety Factor

- ***Confidence in Subsurface Data (Particularly Soil Strength Value)***
- ***Stability Analysis Method***
- ***Consequences of Failure***

Slide 5-1-19

Explain that safety factors for specific projects may be increased above the minimum recommended values due to several conditions including those in this list. Caution the audience that a designer should not indiscriminately increase the safety factor. The economic consequence of safety factor increase can be significant to the point where projects are not feasible. The cost of an adequate site investigation and a competent design are far less than use of excessive safety factors.



Slide 5-1-20

Funny slide to show that garbage in equals garbage out. Relate back to how important data collection was in previous lessons.

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Failure Analysis Methods

- ***Rule of Thumb***
- ***Hand Solutions***
- ***Computer Programs***

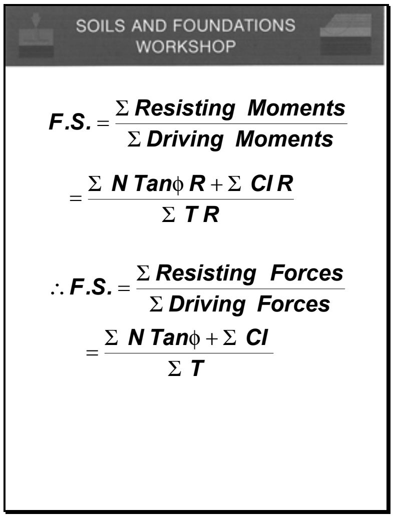
Slide 5-1-21

Comment on the three methods of performing circular analysis.

The rule of thumb is only used for preliminary estimates and to see if more comprehensive analysis is needed.

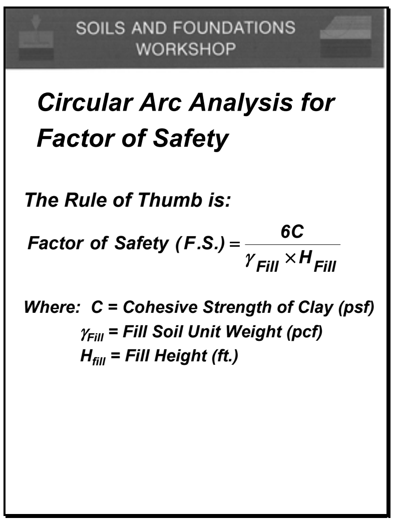
Hand solutions are only possible for the most simplistic type of circular analysis and even then cannot be used for final design due to the extreme amount of computation effort needed to find the critical failure surface. Hand solutions are most commonly used to provide a check on the results of computer analyses.

Numerous computer program exist for circular stability analysis of slopes. The instructor will later demonstrate a program offered by FHWA for stability analysis.



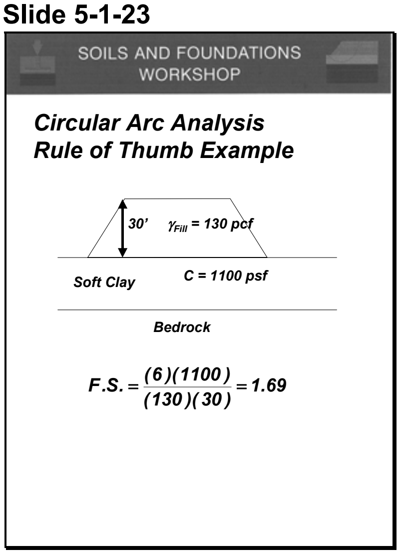
Slide 5-1-22

Explain that circular analysis is based on the concept that a rigid block can fail on a circular shear plane. Rotation occurs about an assumed center of rotation. The factor of safety against failure is found by calculating the driving and resisting moments about an assumed center of rotation. However in simplistic hand analyses, the lever arm for all moments is equal for the circle shape and the safety factor computed from a comparison of driving and resisting forces. The resisting forces are the sum of frictional and cohesion forces. The driving (overturning) force is the net of positive and negative driving forces on either side of the center of rotation.



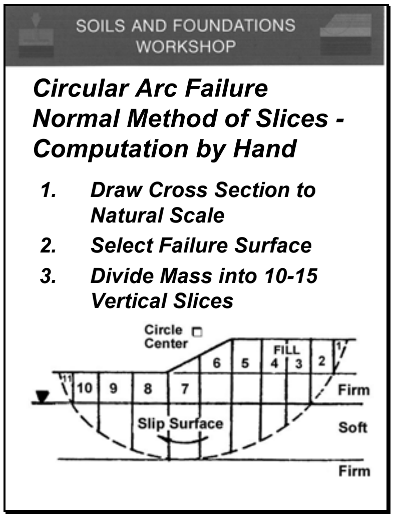
Slide 5-1-23

Explain the rule of thumb concept and the example computation. Mention that any rule of thumb must be used with caution. In this case, a safety factor less than 2.5 is a flag to the designer that a more sophisticated analysis is required. Do not rely on rules of thumb for final design.



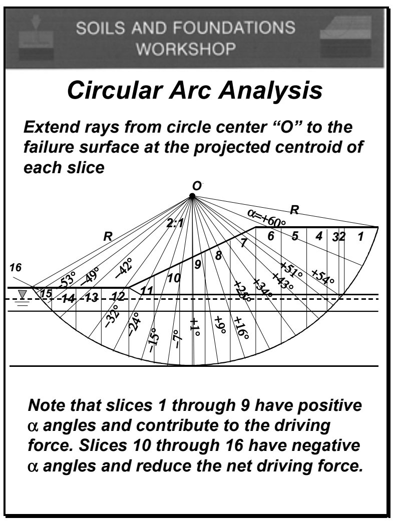
Slide 5-1-24

Demonstrate the computation of embankment safety factor using the rule of thumb. Ask students what errors they see connected with this method of analysis.



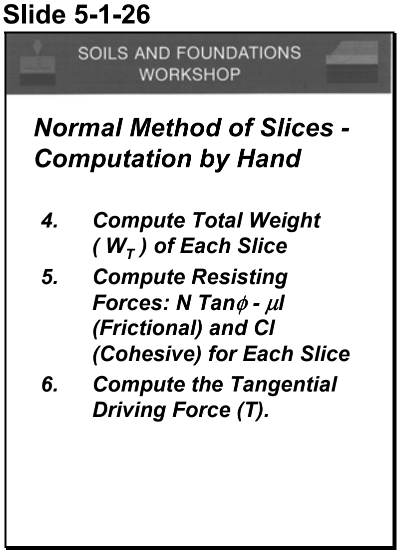
Slide 5-1-25

Introduce the normal method of slices. State that this method is the most basic circular procedure that can be performed by hand. The method has some theoretical shortcomings which tend to make the results conservative; particularly where granular soil layers are present. However the method is straightforward and was selected for this course as computation of both driving and resisting forces can be easily understood. Selection of the first trial circle location is done by experience with the circle center positioned above the mid-point of slope and the radius extending to the base of soft material. Many trials are needed to approach the critical failure location.



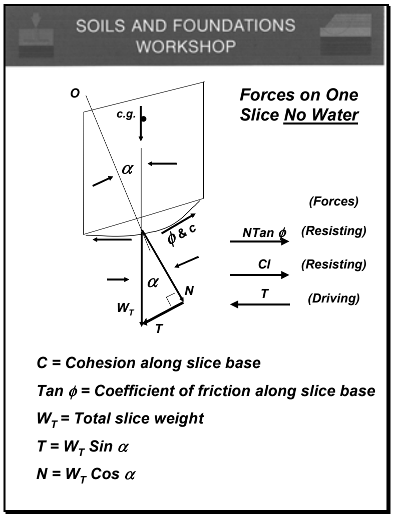
Slide 5-1-26

The magnitude of both the normal and tangential forces will depend on the angle measured in both directions from a vertical line drawn from the circle center.



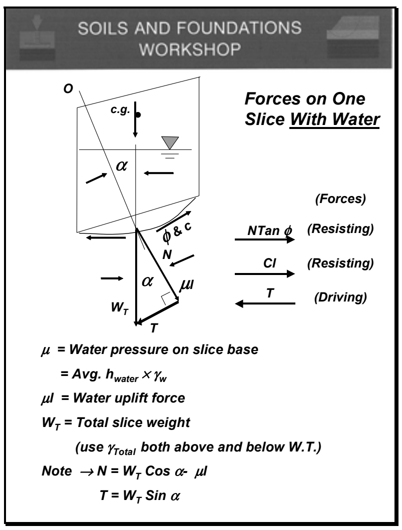
Slide 5-1-27

Explain the computation of resisting and driving forces. Stress that these computations are based on a 1' thick slice, i.e., a 2-dimensional analysis.



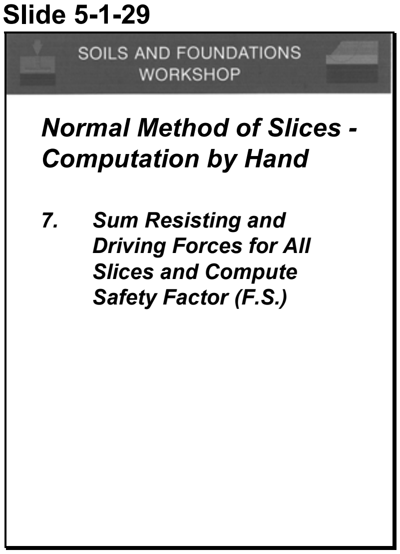
Slide 5-1-28

Explain the graphical concept of driving and resisting forces. Note that we will first consider a situation where no water table exists within the failure mass. Explain that the block (slice) shown is on the driving side of the circle center and will tend to move down to the left due to the weight component acting down the incline. However frictional and cohesive forces at the interface between the block and the material on which the block is rotating will resist that movement.



Slide 5-1-29

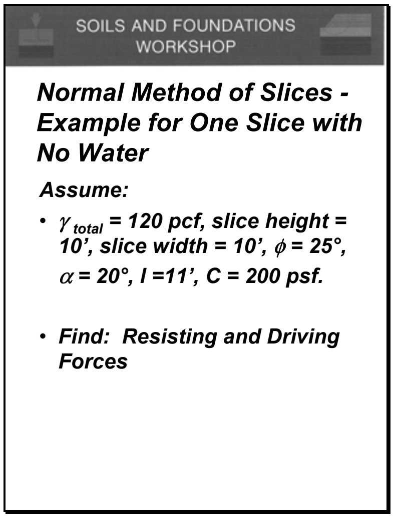
Explain the water table affects only the frictional resisting force. Note that the water force is proportional to the average height of water above the base of the slice. The water force reduces the frictional resistance.



Slide 5-1-30

Explain that resisting forces for all slices are always positive and are simply summed. Driving forces are positive on the driving side of the circle center and negative on the resisting side of the circle center. The driving forces for each slice are summed algebraically to find the net driving force. Students can also observe the net amount of driving and resisting associated with each slice to find which slices have the greatest impact on stability.

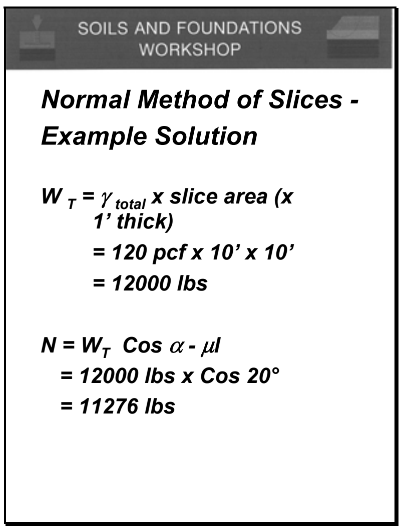
Instructor: * Go to Flip Chart or Chalkboard. Repeat information shown in slides 25 through 30 by drawing an embankment cross section, dividing the slices, drawing the rays and α angle, and showing the W_t, N and T vectors



Slide 5-1-31

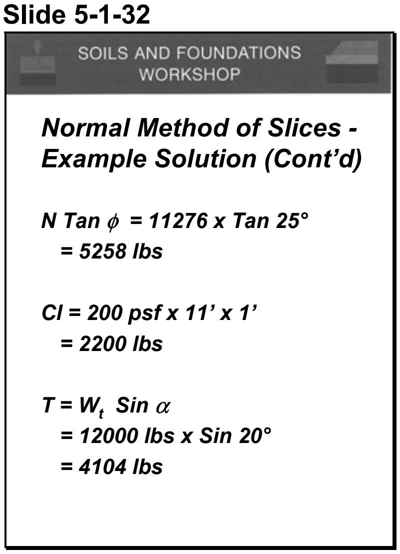
Explain the example problem. Mention that the instructor will compute the component forces and that the group will then sum the appropriate forces to find the total resisting and driving forces.

After explaining the example, ask the group if this slice is located on the driving side of the center or the resisting side of the center. Answer is the driving side as the α angle is positive. A negative angle denotes the slice is on the resisting side.



Slide 5-1-32

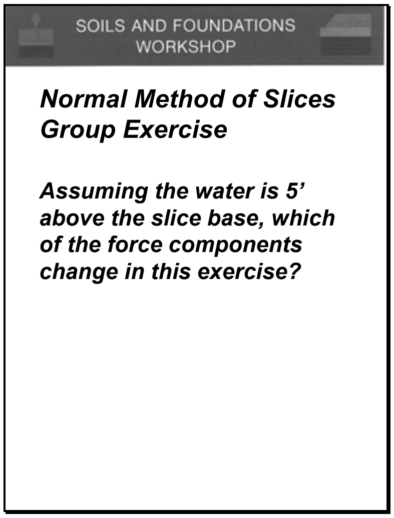
Proceed with the computation of the component forces on the slice. Note that the computation for is based on the assumption that a one foot thick slice is being analyzed.



Slide 5-1-33

After completing the explanation of the computation, ask the group what are the total resisting and driving forces for this slice. Ask if the total forces indicate that this slice is tending to resist movement or promote movement. Answer is resist as the total resisting force is greater than the total driving force.

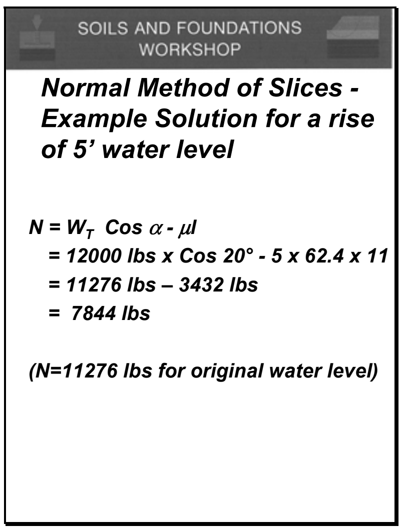
Also remind the group that this is only one of the 10-15 slices that comprise a hand analysis. The forces from all slices need to be calculated and totaled to find the safety factor for this trial circle. Students need to understand that much time and effort is needed to do hand analysis and that many trials are needed to find the most critical circle for a given problem.



Slide 5-1-34

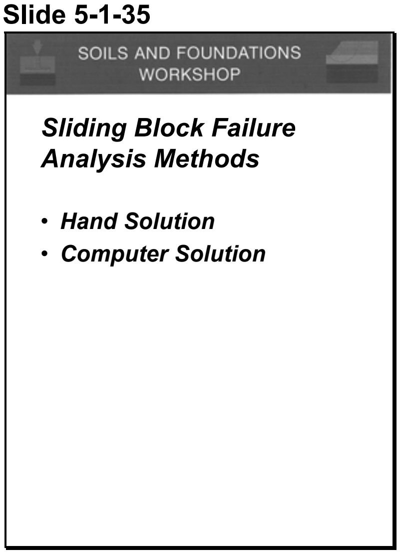
After explaining the exercise, put the previous overhead on the screen. When the group produces the answer (frictional force) ask how the 5' water height would be accounted for in the equations. The correct answer is to include the μ_L term in the Normal Force N.

Also be prepared to field questions on why the cohesion and driving force are not affected by the change in water table, (cohesion based on bond between particles, not seasonal change; driving force based on total weights, not effective weights).



Slide 5-1-35

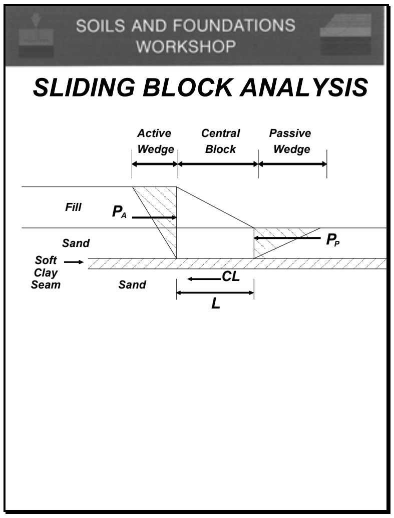
Proceed with the computation (N=11276 lbs for original water level) of the component forces on the slice. Note that the computation for is based on the assumption that a one foot thick slice is being analyzed.



Slide 5-1-36

The sliding block method is a simple, straightforward analysis that can be performed quickly by hand analysis. The block analysis is directly related to the earth pressure concepts used in retaining wall design. This makes the block analysis a good teaching tool to explain basic stability concepts. Mention that a student exercise will follow the explanation of the block method.

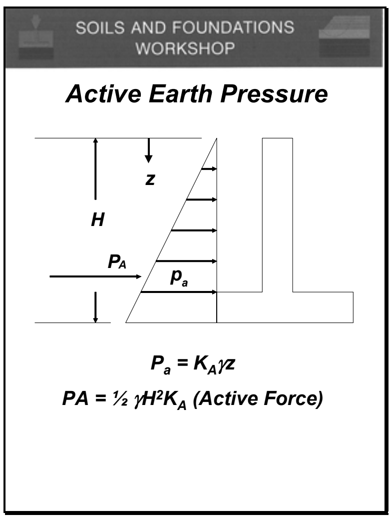
Multiple trials are generally required to find the most critical failure surface, similar to the circular method. Since the block analysis is most commonly used for thin weak layers, the number of trials is usually less than for circular procedures. However computer programs for block stability analysis are recommended for final design. We will demonstrate an FHWA program after completion of this topic.



Slide 5-1-37

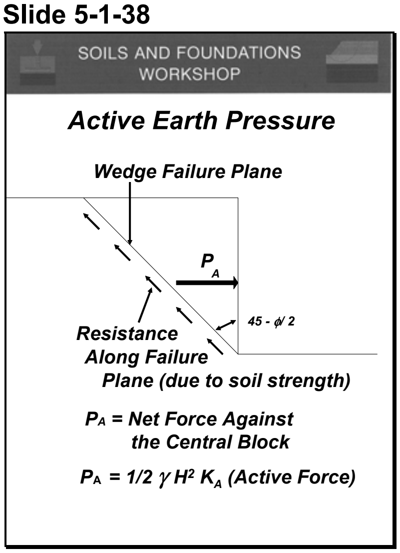
Mention that the sliding block analysis has three component sections that affect the overall stability of the mass; the active wedge that drives the failure, the central block that slides in the soft clay, and the passive wedge that resists movement of the central block. Mention again that this is the situation that you will ask the students to analyze in the student exercise.

Relate the simple Rankine sliding block analysis to basic retaining wall theory where the central block is the wall mass that is acted on by the active and passive forces. Ask who is familiar with retaining wall analysis and then proceed to the next series of overheads to explain the theory.



Slide 5-1-38

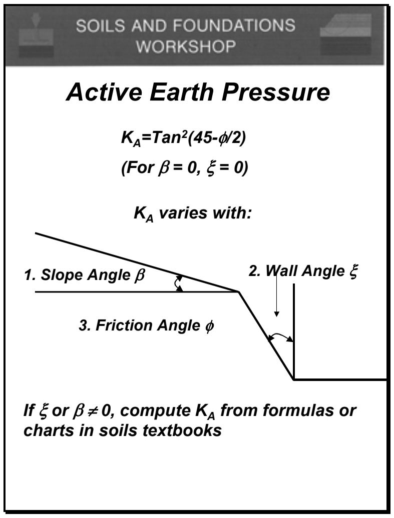
The active earth pressure against a wall is commonly shown as a pressure diagram. This diagram is similar to an overburden pressure diagram except the vertical pressure has been transformed into a horizontal pressure, p_a, by multiplying P_o times the lateral earth pressure coefficient, K_A. The active force against the wall is the area of the pressure diagram for the height of the wall.



Slide 5-1-39

The basis of the active earth pressure concept is that the soil behind the wall will try to fail in a wedge shape. The wedge creates the triangular pressure diagram against the wall. In the case of the sliding block analysis, the pressure diagram is applied to the central block. Note that the force against the central block is calculated the same way as for a wall analysis.

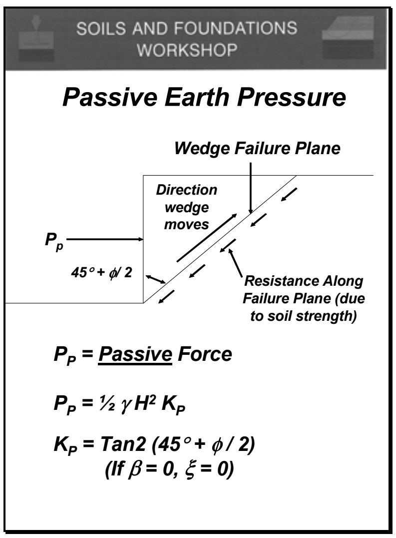
Note that the angle of the failure surface is directly related to the friction angle.



Slide 5-1-40

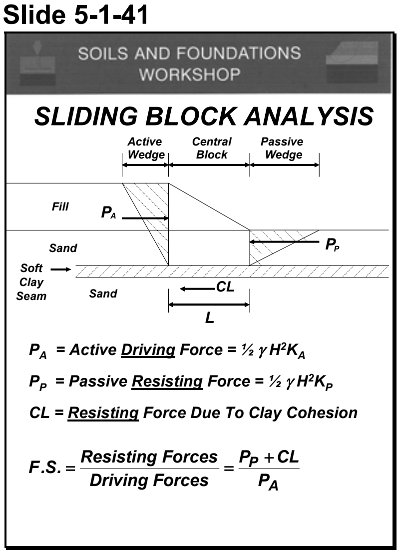
The formula for the Rankine earth pressure coefficient, K_A, is shown for the most basic case, I.e., vertical face and horizontal backslope. This equation will be used in this class. Note that the coefficient is directly related to the friction angle.

Also note that the coefficient varies depending on the angle of the wall and the angle of the backslope. Formulas and charts for these situations are beyond the scope of this course but can be found in most textbooks.



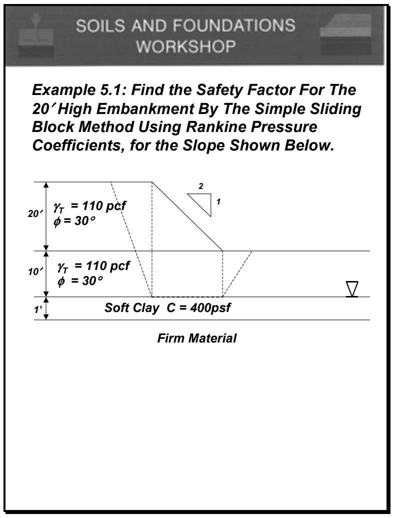
Slide 5-1-41

A similar explanation can be made for the passive pressure. In this case the wall or central block must move the passive wedge up the failure plane before failure can occur. Explain the equation shown and note the equation is the same for both wall analysis and for the sliding block analysis.



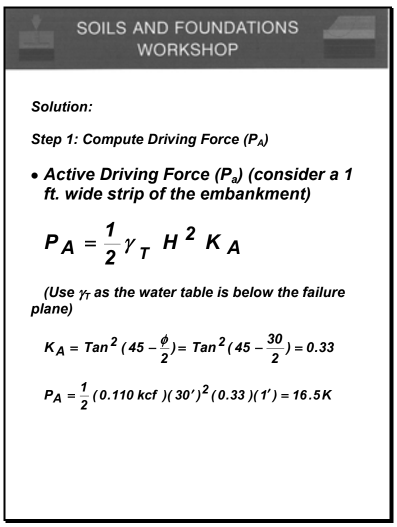
Slide 5-1-42

Complete the conceptual explanation of the sliding block analysis by returning to the block overhead and applying the active and passive concepts that were just explained. Focus on computation of resisting and driving forces to find the safety factor for the block.



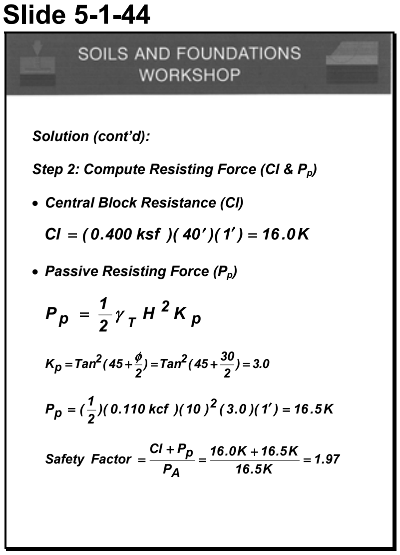
Slide 5-1-43

Demonstrate the solution process for a simple sliding block problem in an example. Get students thinking about the impact of driving and resisting forces on stability.



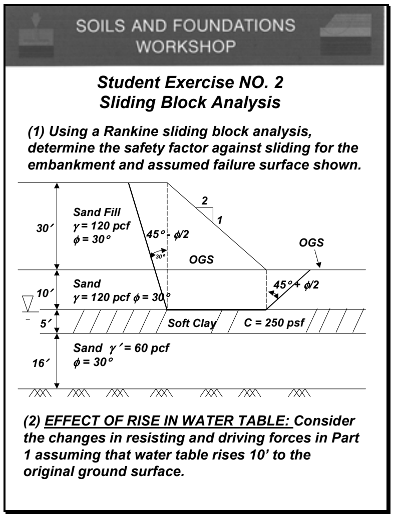
Slide 5-1-44

Demonstrate the solution process for a simple sliding block problem in an example. Get students thinking about the impact of driving and resisting forces on stability.



Slide 5-1-45

Demonstrate the solution process for a simple sliding block problem in an example. Get students thinking about the impact of driving and resisting forces on stability.



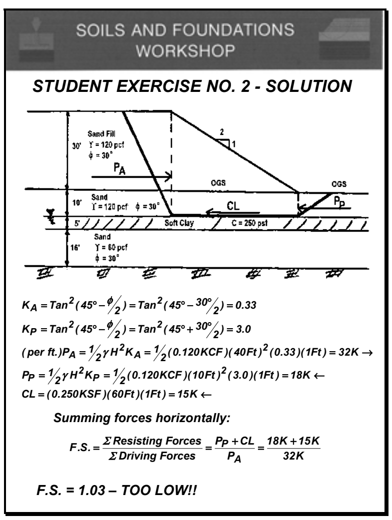
Slide 5-1-46

Ask students to do exercise 2. The exercise involves computation of the safety factor for both a simple embankments over soft ground and then consideration of a situation where the water table rises.

This exercise will test the students on simple stability analysis concepts and computational procedures. Instructor selects one team to put the answer to part 1 on a flip chart and explain to the group. Pertinent questions should be used to test learning of the team and the audience.

Then question the group on the effect of the water table rise. Then show solution for part 2. Do not explain in detail but focus on why water table rise decreases safety factor (resisting forces decrease much more than driving forces). The exercise shows how water can dramatically affect slope stability. Underlying message is that the water level must be determined accurately during site investigation.

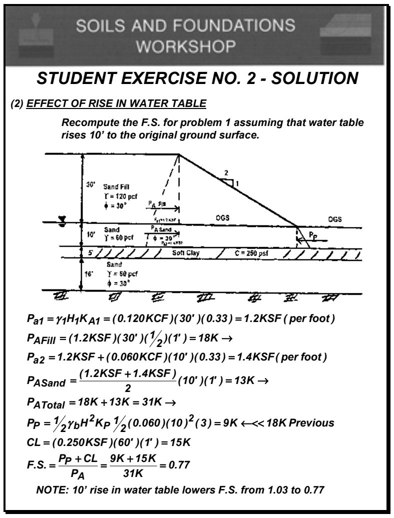
Please refer to the end of the lesson for this exercise.



Slide 5-1-47

Solution to exercise 2 part 1.

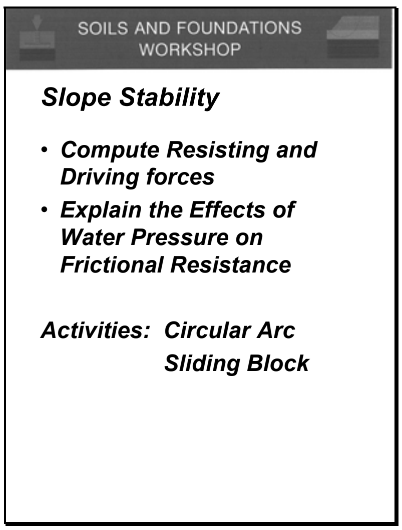
Please refer to the end of the Participant Workbook for the solution to this exercise.



Slide 5-1-48

Show solution to part 2 of the exercise 2. Do not focus on the details of the solution.

Please refer to the end of the Participant Workbook for the solution to this exercise.



Slide 5-1-49

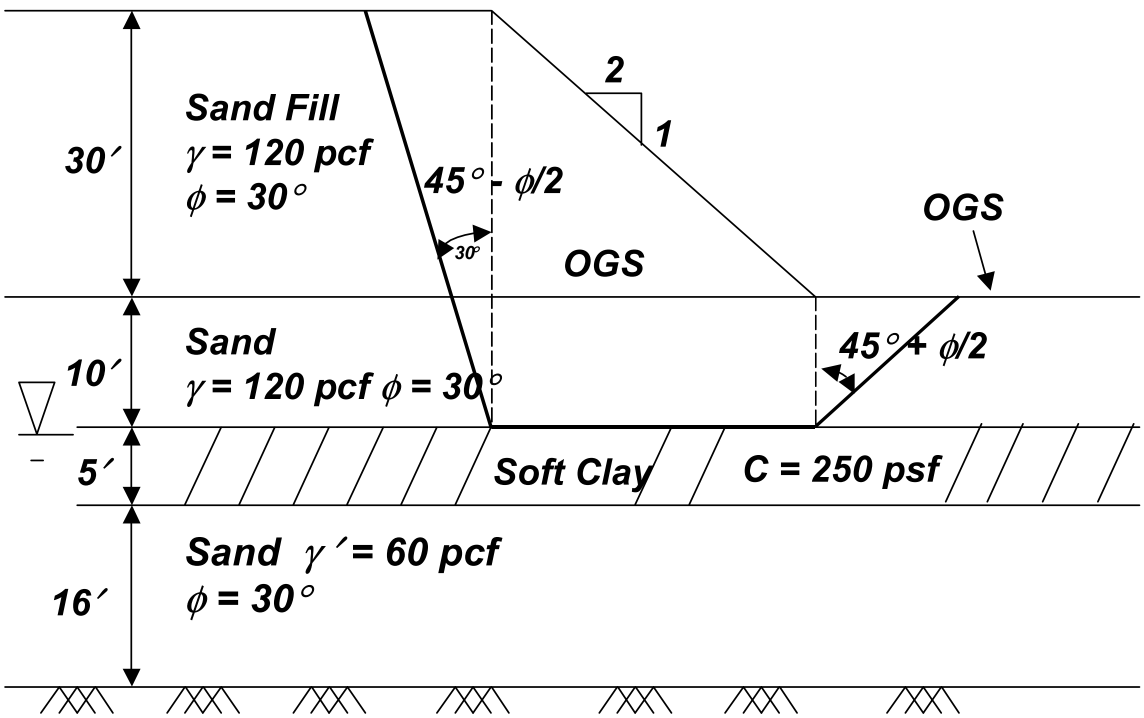
Restate the objectives of this lesson topic. Then proceed to demonstrate the FHWA RSS program and the proprietary XSTABL program. Stress the need to use computerized solution to stability problems but mention that hand analysis is still the best method to check the results of a computer solution.

This demonstration is best done after a break if possible as the equipment set-up can be time consuming (particularly for the video display device). The instructor should prepare for this demonstration the previous day if possible to iron out any kinks in the operation of the equipment or compatibility of the computer to the software.

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise NO. 2
Sliding Block Analysis

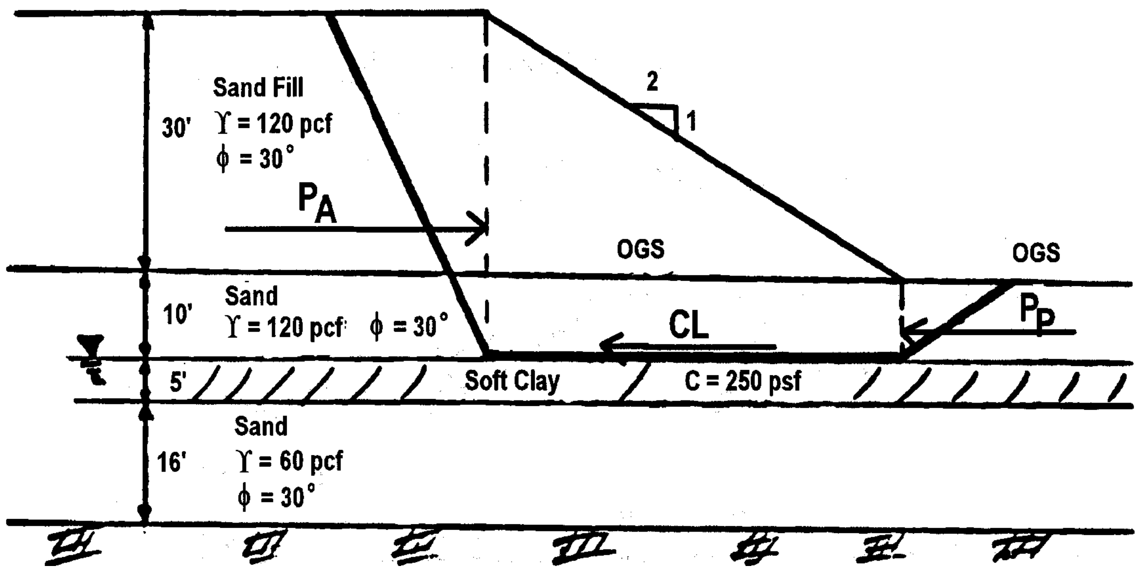
(1) Using a Rankine sliding block analysis, determine the safety factor against sliding for the embankment and assumed failure surface shown.



(2) <u>EFFECT OF RISE IN WATER TABLE:</u> Consider the changes in resisting and driving forces in Part 1 assuming that water table rises 10’ to the original ground surface.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 2 - SOLUTION



$$K_A = Tan^2(45° - \phi/2) = Tan^2(45° - 30°/2) = 0.33$$

$$K_P = Tan^2(45° - \phi/2) = Tan^2(45° + 30°/2) = 3.0$$

$$(per\ ft.)P_A = 1/2\,\gamma H^2 K_A = 1/2(0.120KCF)(40Ft)^2(0.33)(1Ft) = 32K \rightarrow$$

$$P_P = 1/2\,\gamma H^2 K_P = 1/2(0.120KCF)(10Ft)^2(3.0)(1Ft) = 18K \leftarrow$$

$$CL = (0.250KSF)(60Ft)(1Ft) = 15K \leftarrow$$

Summing forces horizontally:

$$F.S. = \frac{\Sigma\ Resisting\ Forces}{\Sigma\ Driving\ Forces} = \frac{P_P + CL}{P_A} = \frac{18K + 15K}{32K}$$

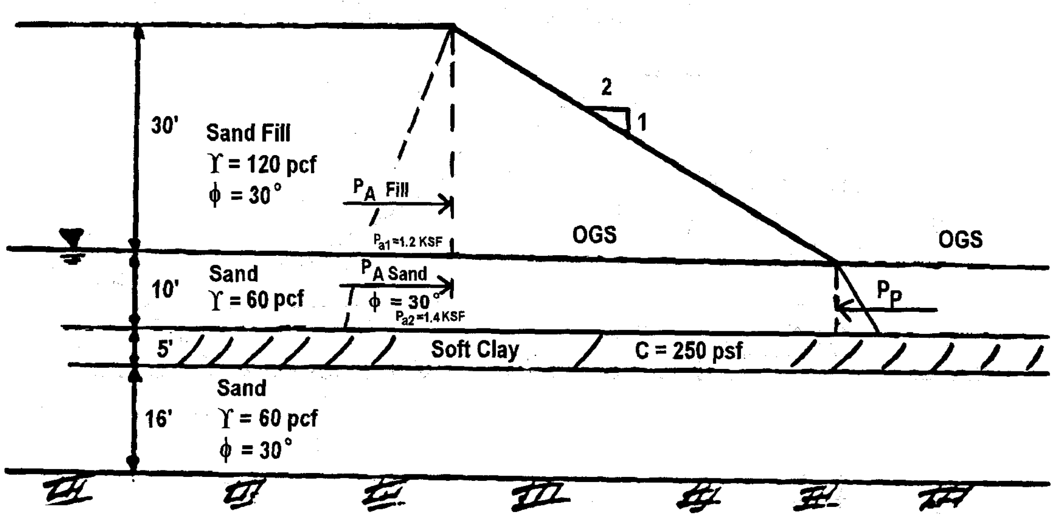
F.S. = 1.03 – TOO LOW!!

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 2 - SOLUTION

(2) EFFECT OF RISE IN WATER TABLE

Recompute the F.S. for problem 1 assuming that water table rises 10' to the original ground surface.



$$P_{a1} = \gamma_1 H_1 K_{A1} = (0.120KCF)(30')(0.33) = 1.2KSF\ (per\ foot)$$

$$P_{AFill} = (1.2KSF)(30')(1/2)(1') = 18K \rightarrow$$

$$P_{a2} = 1.2KSF + (0.060KCF)(10')(0.33) = 1.4KSF\ (per\ foot)$$

$$P_{ASand} = \frac{(1.2KSF + 1.4KSF)}{2}(10')(1') = 13K \rightarrow$$

$$P_{ATotal} = 18K + 13K = 31K \rightarrow$$

$$P_P = 1/2\,\gamma_b H^2 K_P\ 1/2(0.060)(10)^2(3) = 9K \leftarrow << 18K\ Previous$$

$$CL = (0.250KSF)(60')(1') = 15K$$

$$F.S. = \frac{P_P + CL}{P_A} = \frac{9K + 15K}{31K} = 0.77$$

NOTE: 10' rise in water table lowers F.S. from 1.03 to 0.77

LESSON 5

TOPIC 2

Solutions to Slope Instability

SOLUTIONS TO SLOPE INSTABILITY

Lesson 5 - Topic 2

Slide 5-2-1

The question to pose to the students now is “What do we do if we detect a potential stability problem?” Name some potential solutions to slope stability problems.

SOLUTIONS TO SLOPE INSTABILITY

1. Discuss Solutions to Stability Problems

ACTIVITIES: Stability Problem Solving

Slide 5-2-2

State objective. Alert students that the activity will be to suggest solutions to stabilize the embankment in the previous sliding block exercise.

Solutions to Slope Stability Problems

- ***Change Alignment***
- ***Lower Grade***
- ***Counterberm***
- ***Excavate & Replace Weak Soil***

Slide 5-2-3

Introduce methods of solution for stability problems. Mention to the students that you will present examples for all these treatments except change of alignment (which you should briefly discuss while this slide is on the screen).

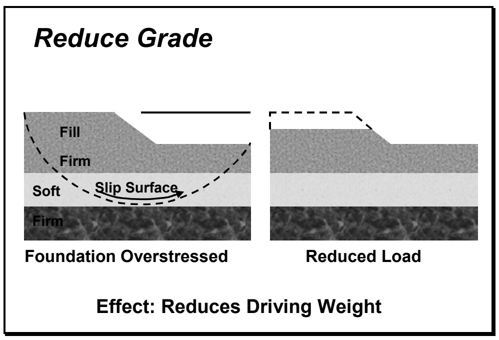
In every example (except change of alignment where no example will be discussed) stress that either resisting or driving forces are affected by the remedial treatment.

Use schematics to permit understanding of stabilization concepts. Use case histories to show real life treatment procedures. Local case histories may be substituted as desired for the examples that follow.

Solutions to Slope Stability Problems (Cont'd)
- ***Stage Construct Fill***
- ***Displace Weak Soil***
- ***Ground Improvement***
- ***Lightweight Fill***

Slide 5-2-4

Continue with methods of solution for stability problems. In every example stress that either resisting or driving forces are affected by the remedial treatment. Use schematics to permit understanding of stabilization concept and case histories to show real life treatment procedure. Local case histories may be substituted as desired for the examples.



Slide 5-2-5

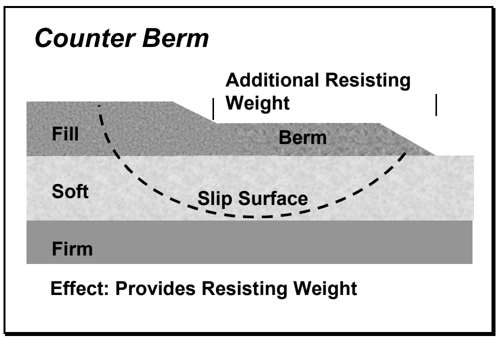
Reducing the grade reduces the driving force.

Slide 5-2-6

This case history involves an embankment failure adjacent to a railroad. Note the heave of the ground and the railroad bed. Note the misalignment of the tracks that caused the speed of the trains to be reduced to 5 mph in this area. A fast solution was needed to permit the railroad to realign the tracks and restore normal services.


Slide 5-2-7

Discussions with the roadway designer indicated that the original grade of the ramp had been raised to accommodate the placement of excess project materials. The grade was subsequently lowered to the original elevation and the slope movement stopped.

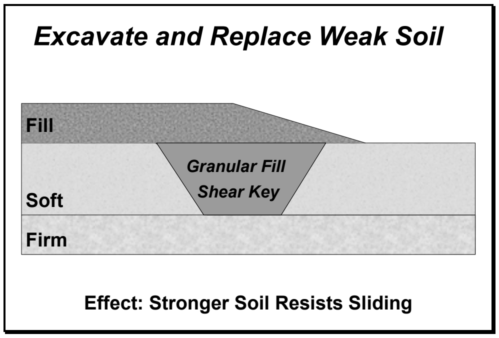


Slide 5-2-8

The berm solution adds weight to the resisting side of the center of the circle. This weight will increase the resisting forces and may reduce the net driving force for original critical failure surfaces. The most critical failure surface is changed by placement of the counter berm. The new critical surface should exit beyond the toe which results in an increase in resistance.


Slide 5-2-9

This counter berm is placed at the toe of slope and is composed of rock. Note that the length and height of the berm must be designed. Also the unit weight assumed for the berm in designed must be checked in construction.

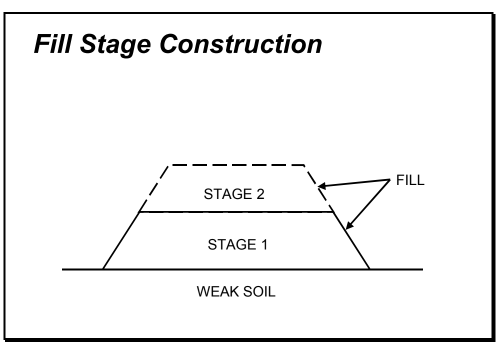


Slide 5-2-10

The shear key treatment involves the removal of soft soils and replacement with granular soils generally in an area under the slope of a planned embankment. The key generally is excavated to the full depth of the soft soil and “keyed” into the underlying firm soil. The later placement of the embankment will cause increased normal forces in the shear key and therefore increased shear strength to resist failure through the shear key.


Slide 5-2-11

This shear key is under construction in an excavated trench. Note that rock is the preferred material to use in a shear key due to good frictional properties and ease of placement in a confined, often wet, area.

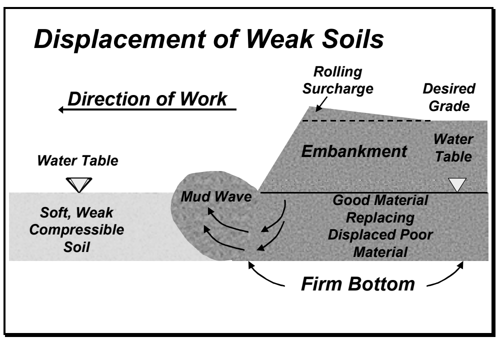


Slide 5-2-12

Stage construction of fills is usually done over soft soils that will exhibit strength gain with time due to the increased load. The objective is to increase the resisting force in the soft soil. The designer uses soil test data to determine the initial height of fill that can be safely placed over the soft soil. Then the designer determines the strength gain in the soft soil that will occur with consolidation under the initial fill. The designer then determines how much additional fill can be placed for the increased foil strength. Often several stages of placement are needed to achieve final grade.

Slide 5-2-13

Stage construction should always be monitored with geotechnical instrumentation to insure that the consolidation is occurring in the soft soil as planned and that the fill height rate of placement is acceptable.

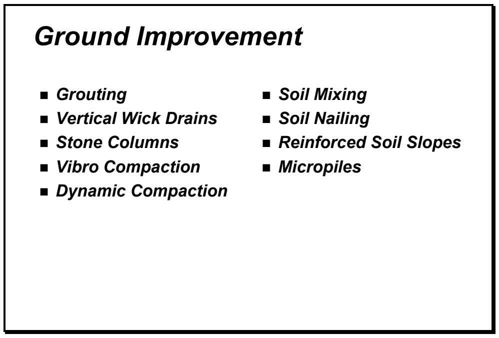


Slide 5-2-14

Displacement of soft soils is accomplished by purposely building the fill to such a height that a controlled shear failure occurs. This procedure increases the resisting forces as the embankment material replaces the soft soils. The fill is slowly advanced in one direction to cause complete displacement of the soft soil. The mud wave that occurs at the leading edge of the fill must removed to prevent soft material from becoming entrapped under the advancing fill.

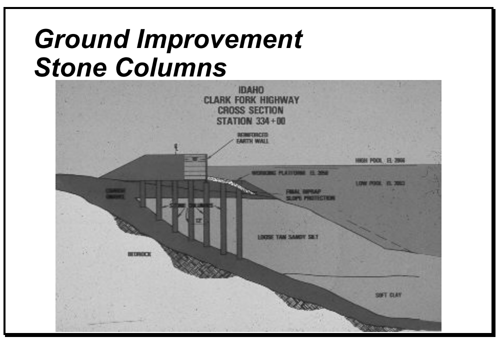
Slide 5-2-15

This displacement project in Idaho involved a fill construction over very soft soils in a lake. Note the mud waves occurring in the lake. These mud waves had to be removed as they surfaced to prevent trapping soft soil under the fill.



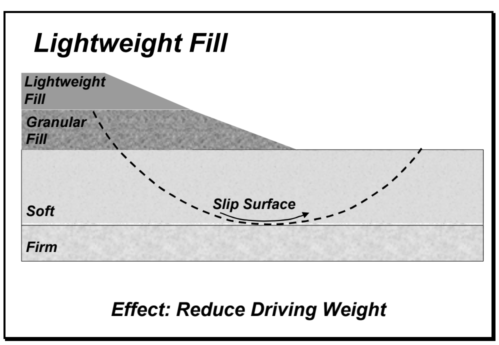
Slide 5-2-16

Briefly describe the basic concepts associated with each method. Recommend FHWA Demo 116, Ground Improvements for detailed information on these methods.



Slide 5-2-17

One example of ground improvement is the Clark Fork Highway in Idaho. The original design involved a long sliver fill that extended far into the lake and resulted in low design safety factors. The use of MSE wall reduced the required embankment cross section. The use of stone columns ensured the safety factor and supported the MSE wall and side slope.



Slide 5-2-18

The use of lightweight filling materials reduces the driving force. The materials used in this method are numerous. Important factors to consider in the use of lightweight materials are cost, placement, availability, density, and environmental effect.

Examples of Lightweight Fill Materials

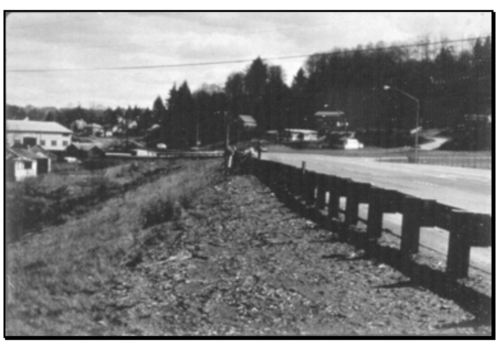
- ***Wood Fiber***
- ***Shredded Tires***
- ***EPS***

Slide 5-2-19

These three materials have been used in highway applications as lightweight materials and will be discussed further. Many other lightweight materials have been used but are beyond the scope of this class. More information can be found in FHWA Demonstration Project 116, publication FHWA-SA-98-086.

Slide 5-2-20

Typical wood fiber project in the Northwest US. Note that materials are spread and compacted with a dozer. Several types of wood fibers are used for fills including sawdust, wood chips, and hog fuel.



Slide 5-2-21

This is a completed view of a wood fiber embankment. Case history data: originally 10' of asphalt pavement by the maintenance to correct settlement problems. Note that the exterior of the wood fiber has been covered with an emulsion, fine-grained soil and vegetation. Experience with uncovering old fiber fills shows that only the exterior of the fiber fill decomposes and creates a "seal" for the interior.

Slide 5-2-22

This shredded tire project in Virginia. Note the tires are delivered to the site and stockpiled. Spreading and compaction is done with tracked equipment as the steel belts can cause significant damage to rolling construction equipment. On this project the shredded tires were placed in alternating layers with soil.

Slide 5-2-23

Note the size of the tire shreds are fairly large. After compaction of the shreds, a soil cover of at least 4’ is placed between the shreds and the pavement section.

Slide 5-2-24

EPS (Expanded Polystyrene), which is also known as Geofoam, is an ultra light weight material. Even the instructor could easily lift a 32 cubic foot block of EPS. (This block only weighed about 40 pounds).


Slide 5-2-25

Construction with EPS only requires basic tools such as a chain saw to trim the block to the desired shape.


Slide 5-2-26

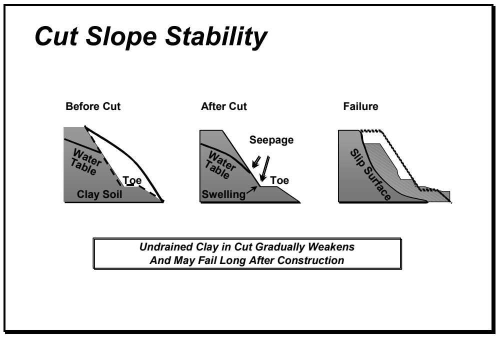
The assembly of the EPS fill occurs quickly as the block are placed in an interlocking pattern and anchored to the previous row with timber hooks. This installation on the I-15 Salt Lake City Project was used as an approach embankment.

Cut Slope Stability

- ***Deep-Seated Failure (clays)***
- ***Shallow Surface "Sloughs" in Saturated Slopes of Clay, Silt and/or Fine Sand***

Slide 5-2-27

Introduce cut slope stability.



Slide 5-2-28

Explain the effect of water on long term cut stability. Remind students of what happens in the lab when a clay sample is taken out of the tube and allowed to expand. Focus on the clay swelling, absorbing more water, and the strength decrease with time.

Solutions to Cut Slope Stability Problems

- ***Flatten or Bench Slope***
- ***Buttress Toe***
- ***Lower Water Table***

Ground Improvement and Biotechnical Stabilization are also potential solutions.

Slide 5-2-29

The first three solutions are the bread and butter solutions used by highway agencies. The latter two solutions are methods that may require specialists for both the design and construction of the solution.

Slide 5-2-30

Show case history of cut stabilization. This is a typical springtime "pop-out" caused by fine-grained soils and a high water table. The soil becomes nearly quick and slides into the ditch. Tell the group that the wrong solution is to simply have maintenance push this material back up the slope. Then ask the audience what their agency does to remedy these problems?

Slide 5-2-31

Mention that the most common solution to the problem is to remove the wet material. Then construct a shallow (4' by 4') rock key at the toe and replace the wet material with rock that is pushed up the slope with a dozer. Note that the dozer will compact the material during the placement.

Slide 5-2-32

Note that the rock key at the toe is absolutely necessary to provide a base to prevent the rock from slipping back down slope due to erosion at the toe. Generally a 4' wide by 4' deep key is constructed beneath the foot of toe.

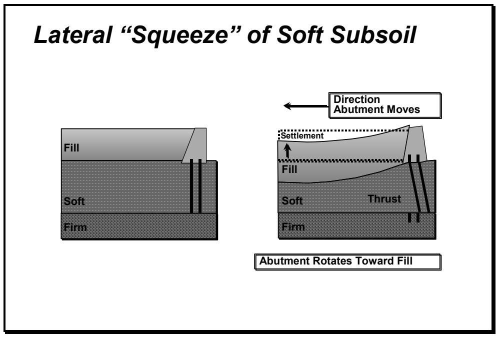
Cut Slopes

Minimum Recommended Safety Factor = 1.50

Cut Slopes may Deteriorate With Time as a Result of Natural Drainage Conditions That Embankments Do Not Experience

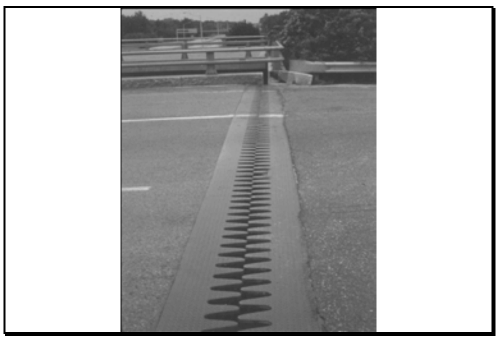
Slide 5-2-33

Explain the need for a higher safety factor for cut slopes.



Slide 5-2-34

Introduce lateral squeeze. Explain that lateral squeeze most commonly occurs in soft ground conditions when a fill is constructed behind a structure on a deep foundation. The fill tends to settle non-uniformly and cause the soft soil to be squeezed toward the foundation. Normally the foundation elements are so close that the soil cannot flow in between. High forces develop on the foundation, which result in movement of the structure. The instructor should comment on the large magnitude of the forces as non-geotechnical engineers commonly misunderstand this concept.



Slide 5-2-35

Show lateral squeeze case history. Begin by noting that the open joint seems a bit unusual as this picture was taken in the middle of the summer. Then point out the far wingwall distortion and ask what is happening? Then show next slide of severe distortion under abutment.

Slide 5-2-36

Show lateral squeeze case history. Note the backward rotation of the abutment has caused the beams to nearly fall off the rockers. Then ask how we could have mitigated this movement.

Lateral Squeeze: Abutment Rotation Can Occur if:

$$\gamma_{FILL} \times H_{FILL} > 3 \times \text{Cohesion}$$

Slide 5-2-37

Explain the limiting condition for occurrence of lateral squeeze.

Lateral Squeeze: How to Prevent Abutment Rotation

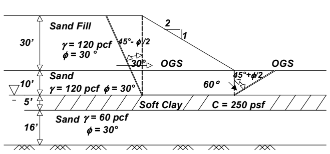
Get Fill Settlement Out Before Abutment Piling are Driven

Slide 5-2-38

Lateral squeeze solution.

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 2
Sliding Block Analysis – Part 3



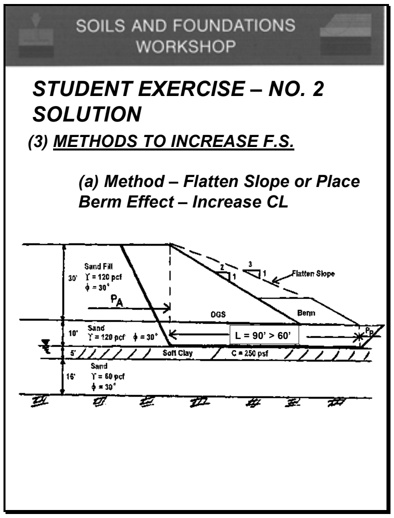
(3) Assuming the F.S., from Part 1, is less than acceptable, state 2 method(s) of making the slope safe.

Explain, with reference to the F.S. equation, why your method <u>increases</u> the factor of safety.

Slide 5-2-39

GROUP EXERCISE After slide presentation on solutions; ask group to apply the knowledge to the previous student exercise for the sliding block. Get the students to focus on changes that occur to the driving and resisting forces for the solutions that they chose. GROUP EXERCISE

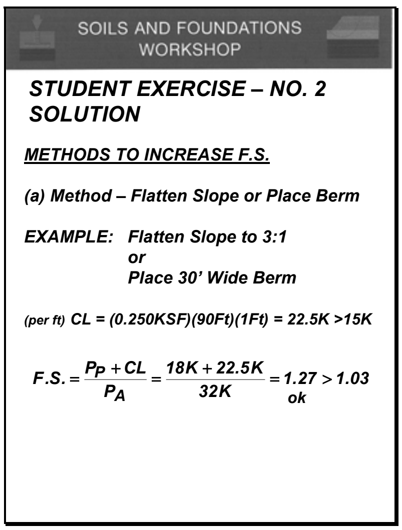
Please refer to the end of the lesson for this exercise.



Slide 5-2-40

Ask secondary questions about solutions; i.e., for berm: ask group how important is compaction, how is berm height determined, and how should berm surface be graded? Compaction must insure that the design density was achieved. Berm height is determined by the height needed to prevent the failure from exiting through the berm rather than forced out beyond the berm and the stability of the berm may need to be checked. Berm surface should be graded to prevent water form ponding at the embankment interface with the berm.

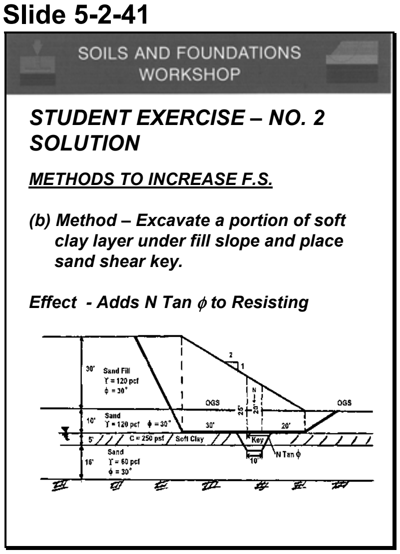
Please refer to the end of the Participant Workbook for the solution to this exercise.



Slide 5-2-41

Ask secondary questions about solutions; i.e., berm ask how important is compaction, how is berm height determined, and how should berm surface be graded? Compaction must insure that the design density was achieved. Berm height is determined by the height needed to prevent the failure from exiting through the berm rather than forced out beyond the berm and the stability of the berm may need to be checked. Berm surface should be graded to prevent water form ponding at the embankment interface with the berm.

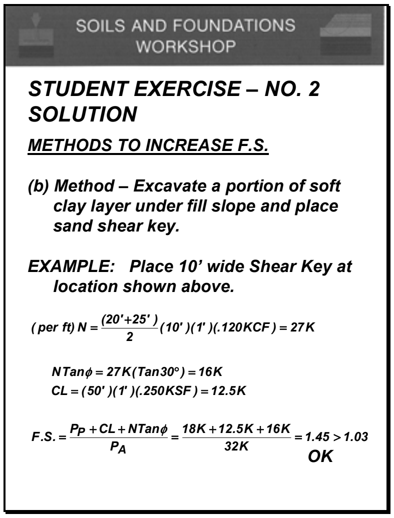
Please refer to the end of the Participant Workbook for the solution to this exercise.



Slide 5-2-42

For shear key ask what is minimum width determined by and where is optimal location for key? Minimum width is determined by both the design analysis and by the equipment that will construct the key. Commonly a key is constructed with a dozer and the key width will be at least the width of the blade, I.e., about 10'.

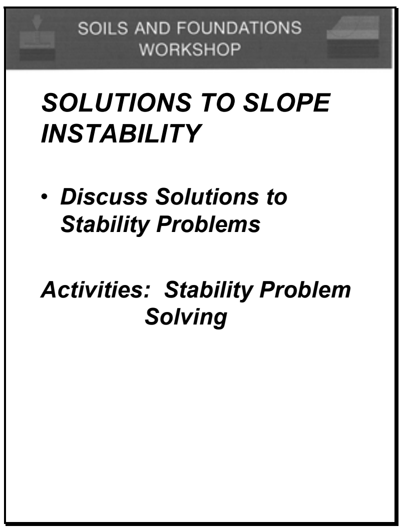
Please refer to the end of the Participant Workbook for the solution to this exercise.



Slide 5-2-43

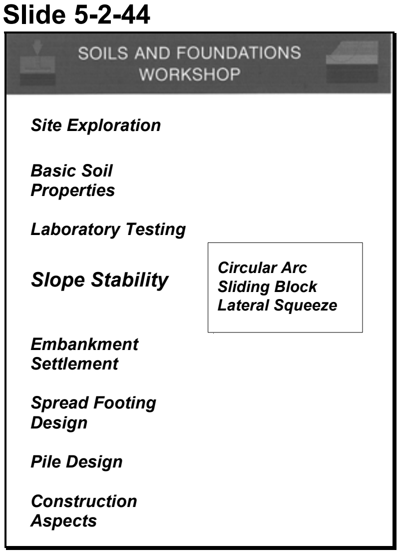
For shear key ask what is minimum width determined by and where is optimal location for key? Minimum width is determined by both the design analysis and by the equipment that will construct the key. Commonly a key is constructed with a dozer and the key width will be at least the width of the blade, i.e., about 10'.

Please refer to the end of the Participant Workbook for the solution to this exercise.



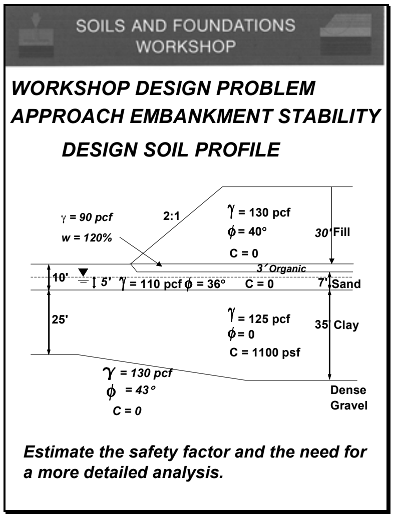
Slide 5-2-44

Review objective for Topic 2. Then go to reference manual and review the sections covered in Topic 2. Then begin the Apple Freeway problem.



Slide 5-2-45

Review data gathering phases for Apple Freeway. Note the first step in design is to assure stability of the embankment.



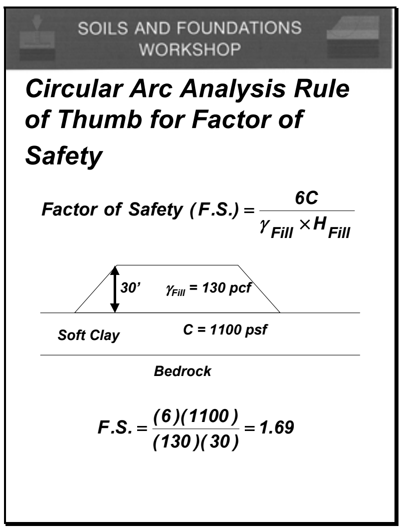
Slide 5-2-46

Use the Apple Freeway to test knowledge of slope stability concepts and solutions.

What type of failure would you expect at this site?

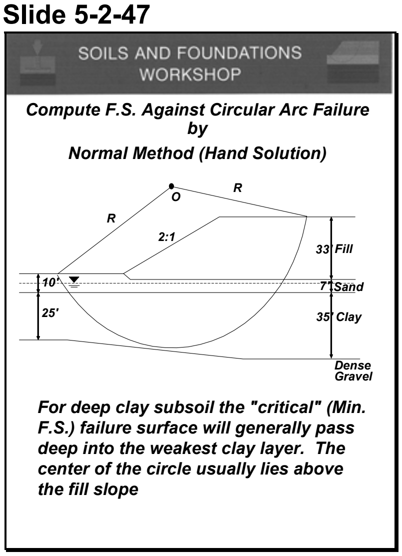
Should you excavate the organic material?

If you do excavate how could you estimate the factor of safety quickly from this profile, and the need for a more detailed analysis?



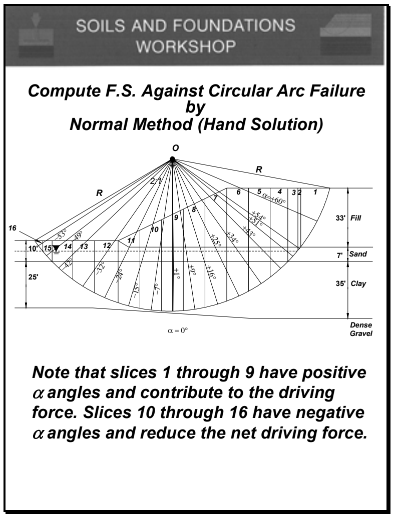
Slide 5-2-47

The answer to the previous question is use the rule of thumb. This computation is shown in the reference manual, page 5-5. If the safety factor is less then 2.5, a more sophisticated analysis is required.



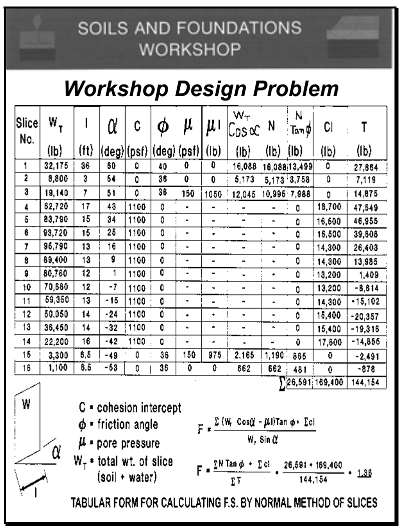
Slide 5-2-48

Discuss the reason the trial circle goes to the soft layer base.



Slide 5-2-49

Discuss how rays (radius) are drawn from the circle center to the centroid of the base of each slice.



Slice No.	W_T (lb)	l (ft)	α (deg)	c (psf)	φ (deg)	μ (psf)	μl (lb)	W_T Cos α (lb)	N (lb)	N Tan φ (lb)	Cl (lb)	T (lb)
1	32,175	36	60	0	40	0	0	16,088	16,088	13,499	0	27,864
2	8,800	3	54	0	36	0	0	5,173	5,173	3,758	0	7,119
3	19,140	7	51	0	36	150	1050	12,045	10,995	7,988	0	14,875
4	62,720	17	43	1100	0	-	-	-	-	0	18,700	47,549
5	83,790	15	34	1100	0	-	-	-	-	0	16,500	46,955
6	93,720	15	25	1100	0	-	-	-	-	0	16,500	39,808
7	96,790	13	16	1100	0	-	-	-	-	0	14,300	26,403
8	89,400	13	9	1100	0	-	-	-	-	0	14,300	13,985
9	80,760	12	1	1100	0	-	-	-	-	0	13,200	1,409
10	70,680	12	-7	1100	0	-	-	-	-	0	13,200	-8,614
11	59,350	13	-15	1100	0	-	-	-	-	0	14,300	-15,102
12	50,050	14	-24	1100	0	-	-	-	-	0	15,400	-20,357
13	36,450	14	-32	1100	0	-	-	-	-	0	15,400	-19,316
14	22,200	16	-42	1100	0	-	-	-	-	0	17,600	-14,855
15	3,300	6.5	-49	0	36	150	975	2,165	1,190	865	0	-2,491
16	1,100	6.5	-53	0	36	0	0	662	662	481	0	-878
										Σ 26,591	169,400	144,154

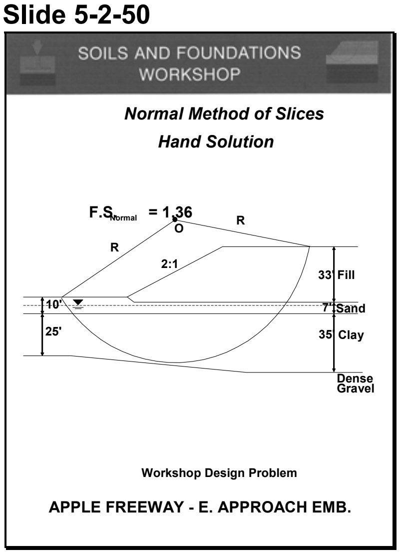
$$F = \frac{\Sigma (W_T \cos\alpha - \mu l)\tan\phi + \Sigma cl}{W_T \sin\alpha}$$

$$F = \frac{\Sigma N \tan\phi + \Sigma cl}{\Sigma T} = \frac{26{,}591 + 169{,}400}{144{,}154} = \underline{1.36}$$

TABULAR FORM FOR CALCULATING F.S. BY NORMAL METHOD OF SLICES

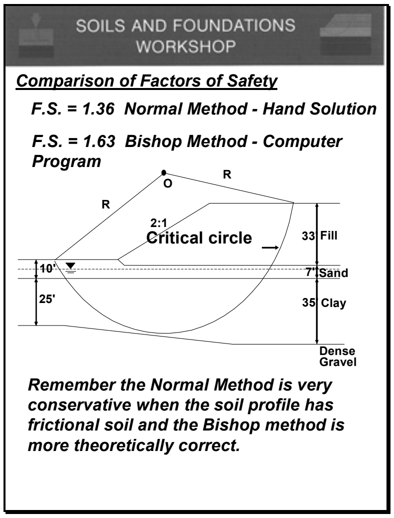
Slide 5-2-50

Show the hand solution and comment on the time for one computation. Note the magnitude of the resisting and overturning forces are computed in the design analysis for a 1' wide slice and that most slides are hundreds of feet wide.



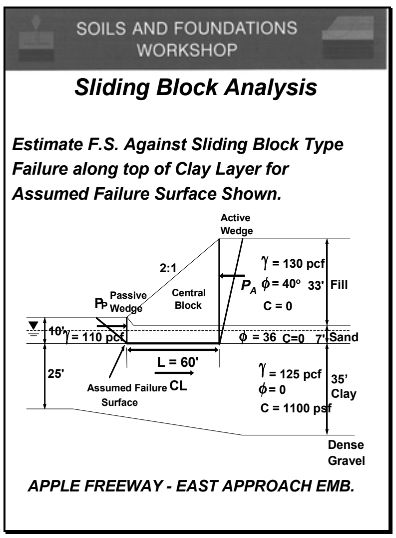
Slide 5-2-51

Discuss the computed safety factor versus what is required for this site.



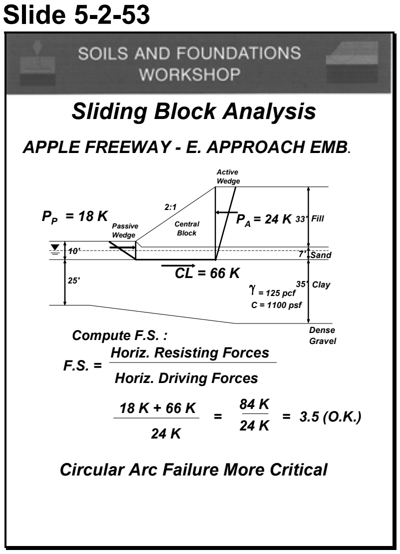
Slide 5-2-52

Discuss how different analyses produce different safety factors and ask which to use.



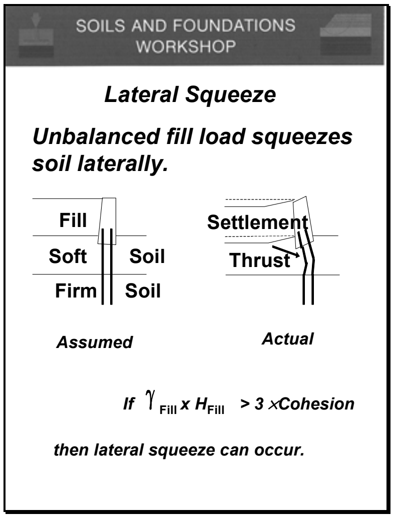
Slide 5-2-53

Ask if we would expect conditions to be favorable for a sliding block failure at this site.



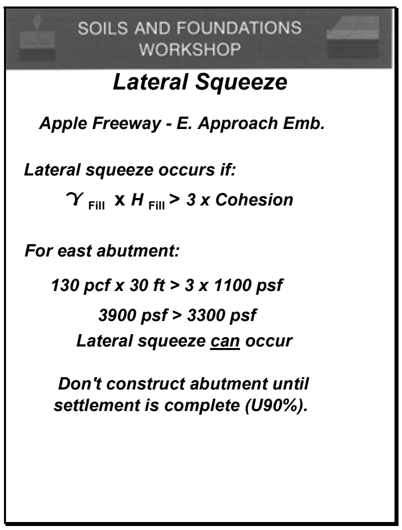
Slide 5-2-54

Show safety factor and ask if this is a critical failure mechanism for this site.



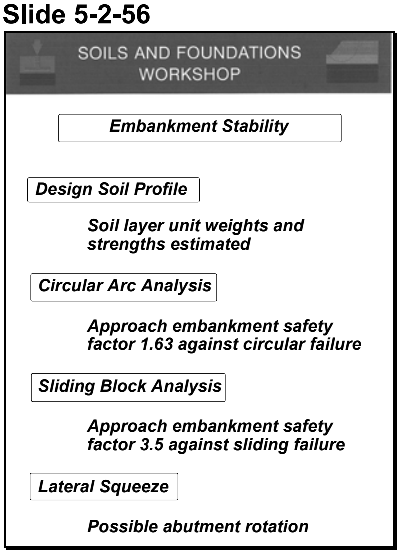
Slide 5-2-55

Ask how to determine if lateral squeeze is a problem at this site?



Slide 5-2-56

Explain lateral squeeze concept and application to Apple Freeway.



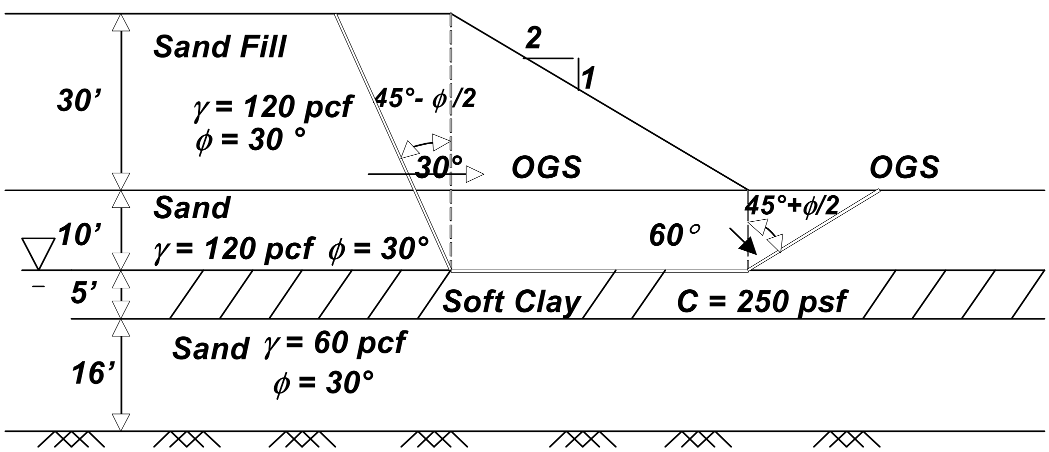
Slide 5-2-57

Review Apple Freeway accomplishments.

Instructor promotes NHI Slope Stability course.

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 2
Sliding Block Analysis – Part 3



(3) Assuming the F.S., from Part 1, is less than acceptable, state 2 method(s) of making the slope safe.

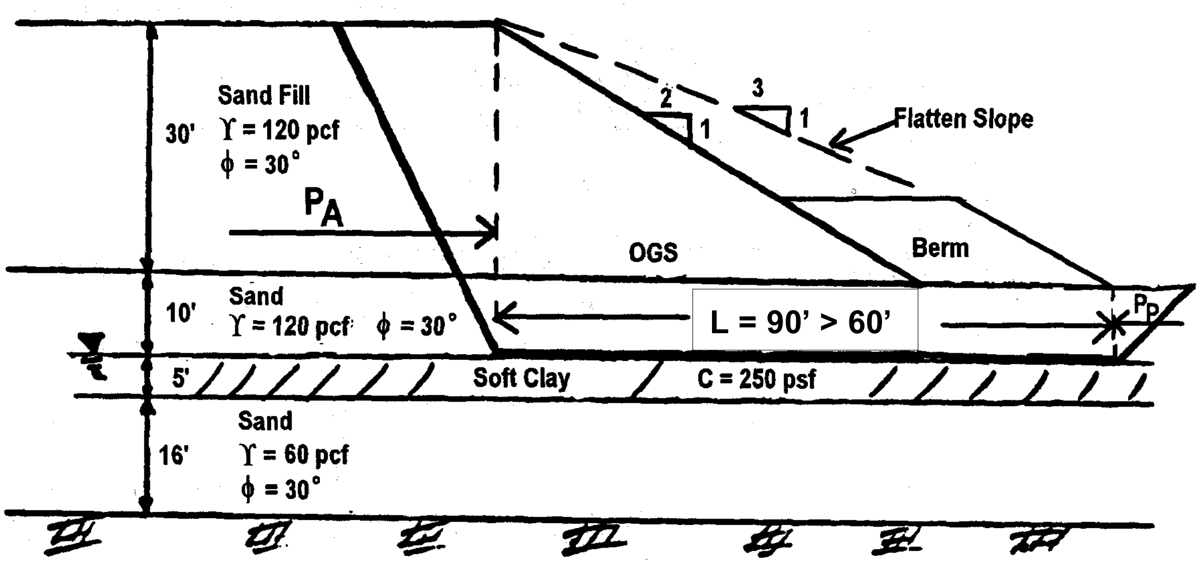
Explain, with reference to the F.S. equation, why your method <u>increases</u> the factor of safety.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE – NO. 2 SOLUTION

(3) METHODS TO INCREASE F.S.

(a) Method – Flatten Slope or Place Berm Effect – Increase CL



SOILS AND FOUNDATIONS
WORKSHOP

STUDENT EXERCISE – NO. 2 SOLUTION

METHODS TO INCREASE F.S.

(a) Method – Flatten Slope or Place Berm

EXAMPLE: ***Flatten Slope to 3:1***
or
Place 30' Wide Berm

(per ft) ***CL = (0.250KSF)(90Ft)(1Ft) = 22.5K >15K***

$$F.S. = \frac{P_P + CL}{P_A} = \frac{18K + 22.5K}{32K} = 1.27 > 1.03$$

ok

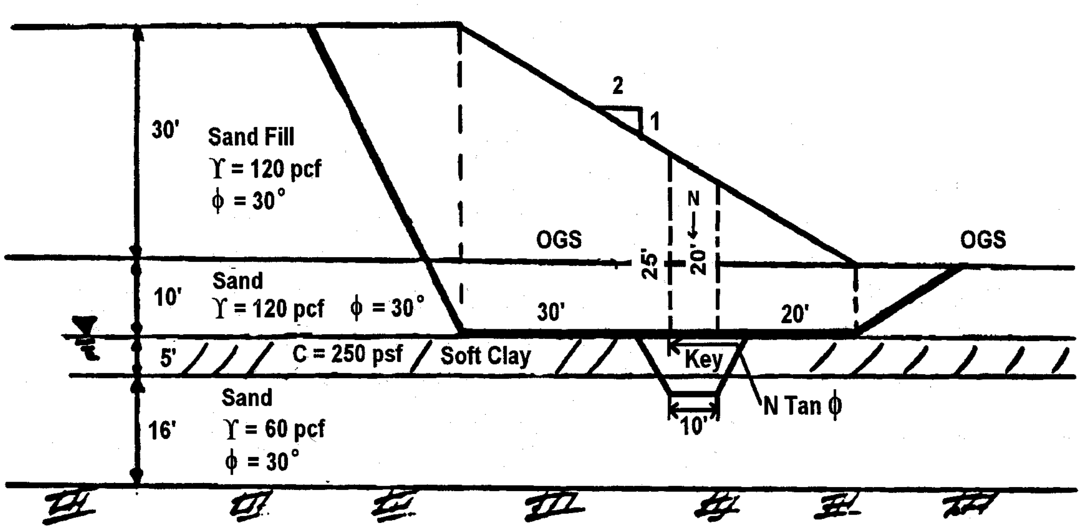
SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE – NO. 2 SOLUTION

METHODS TO INCREASE F.S.

(b) Method – Excavate a portion of soft clay layer under fill slope and place sand shear key.

Effect - Adds N Tan ϕ to Resisting



SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE – NO. 2 SOLUTION

METHODS TO INCREASE F.S.

(b) Method – Excavate a portion of soft clay layer under fill slope and place sand shear key.

EXAMPLE: Place 10' wide Shear Key at location shown above.

$$(per\ ft)\ N = \frac{(20' + 25')}{2}(10')(1')(.120KCF) = 27K$$

$$NTan\phi = 27K(Tan30^\circ) = 16K$$

$$CL = (50')(1')(.250KSF) = 12.5K$$

$$F.S. = \frac{P_P + CL + NTan\phi}{P_A} = \frac{18K + 12.5K + 16K}{32K} = 1.45 > 1.03$$

OK

LESSON 6

TOPIC 1

Embankment Settlement

EMBANKMENT SETTLEMENT

Lesson 6 - Topic 1

Slide 6-1-1

Introduce the settlement lesson and indicate that the lesson will be broken into two parts; first the settlement analysis procedures will be covered then the treatments for settlement will be covered second.

EMBANKMENT SETTLEMENT

1. Estimate Compressibility from Basic Soils Data
2. Calculate Settlement

ACTIVITIES: ***Compressibility Values***
Settlement Analysis

Slide 6-1-2

Lesson objectives

Embankments
Major Design Considerations

- ***Stability***
- ***Settlement***
- ***Effects on the Structure***

Slide 6-1-3

Review that stability issues must be considered first, then settlement and the effects on structures complete the embankment design.

Embankments

- ***End Slope Safety Factor = 1.30***
- ***Side Slope Safety Factor = 1.25***

Slide 6-1-4

Review safety factors required for acceptable stability conditions.

Slide 6-1-5

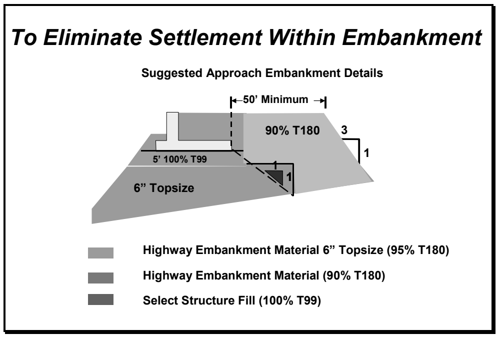
Case history of settlement within embankment. As indicated by adjacent ground topography, this embankment was placed on rock. However note that so much settlement and regrading/repaving has occurred that the guardrail is nearly at pavement level.

Avoid Settlement Within Embankment

- ***No Organic or Miscellaneous Fill Material Allowed***
- ***Control Fine-Grained Material Use***
- ***Require Compaction and Compaction Control Tests***

Slide 6-1-6

Internal consolidation factors.



Slide 6-1-7

Typical cross section of good design to prevent internal consolidation.

Slide 6-1-8

Typical case history of the bump at the end of the bridge. Note the characteristic dip in the guard rail and the patch at the interface between the abutment backwall and the approach fill.

Reasons for "the Bump at the End of the Bridge"

- ***Poor Compaction of Embankment Material Near the Structure***
- ***Migration of Fines into Drainage Material Behind Abutment Backwall***

Slide 6-1-9

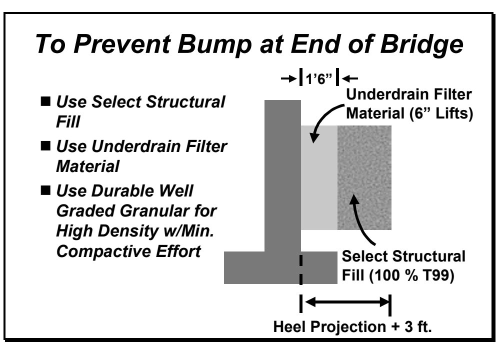
State reasons, and then asks audience how their highway agency prevents the bump at the end of the bridge. The answer you want is "use an approach slab". After either getting that answer or leading the audience to the answer, show the next slide of an approach slab

Slide 6-1-10

Note the use of the slab has only moved the bump to the end of the approach slab. This is not the most effective method to eliminate the bump.

Slide 6-1-11

In order to understand the source of the problem of the bump at the end of the bridge you need to understand the typical construction process for a bridge abutment in fill. Note in this photo the main height of fill only extends partially into the U-shape of the abutment. The final backfill will be placed when the forms are stripped. Note that the backfill area is narrow, the corners cramped and the backfill will be placed against both the back wall and the slope. Proper materials and placement are needed to ensure a non-yielding backfill that will withstand years of drainage from the bridge and the heavy impact of trucks rolling off the bridge.



Slide 6-1-12

Show the recommended solution in cross section and highlight important items to be included in the specifications. Emphasize durability and ask what controls the agency now has on durability of backfill.

Select Material Specifications

■ Specification Item	■ Reason for Item
- 6"-8" Lift Thickness	- Small Compaction Equipment
- Topsize Restriction	- Less than 3/4 Lift Thickness
- Gradation Requirement	- Compactibility

Slide 6-1-13

Focus on what should be included in the specifications and the reason for the item.

Select Material Specification (Cont'd)

■ Specification Item	■ Reason
- Durability	- Minimize Breakdown
- Limit Percent Fines	- Density/Piping
- T99 Density Control	- Small Compaction Equipment
- Compatible to Drain Material	- Prevent Piping

Slide 6-1-14

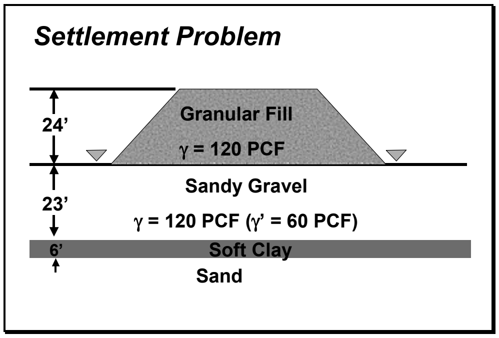
Focus on what should be included in the specifications and the reason for the item.

Avoid Major Subsoil Settlement

- Identify and Provide Treatment for Organic Soils
- Analyze Clay Subsoil Deposits

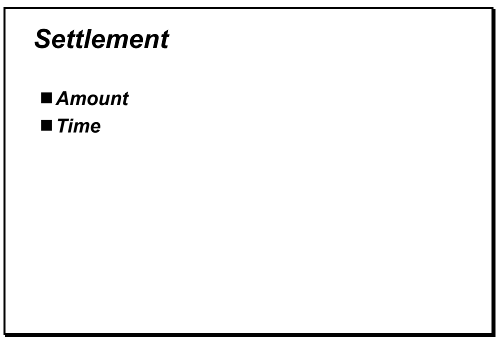
Slide 6-1-15

Begin the analysis portion of subsoil settlement here. Start slowly by building on basic concepts until the student has been shown the entire settlement computation and analysis process over a series of visuals. First introduce the concept of subsoil settlement.



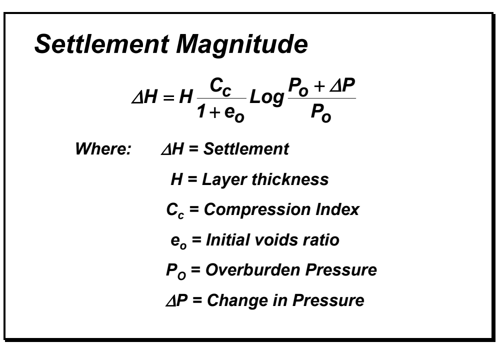
Slide 6-1-16

Show typical problem where subsoil settlement is the main issue. Ask which layer is of most concern to consolidate (clay layer). Then ask what two steps need to be taken before a designer can accurately predict the settlement (take undisturbed tubes in the clay layer and perform consolidation tests).



Slide 6-1-17

Stress that time as well as magnitude must be considered. Stress that the time for settlement is a very important issue for post construction maintenance of the highway facility. Periodic road closure for maintenance result in expenditure of highway funds, delays to traveling public, and bad public relations for the agency. Funds are better spent to assure a adequate design than to repair a poor design.



Slide 6-1-18

Introduce and explain the basic settlement equation. Emphasize the need for good consolidation testing. Ask students how to find each of the terms in the equation (H from soil profile, C_c and e_o from consolidation test, Po from Po diagram and change in pressure from applied load.

Settlement Time

$$t = \frac{TH_V^2}{C_V}$$

Where: t = Time for Settlement

T = Time Factor

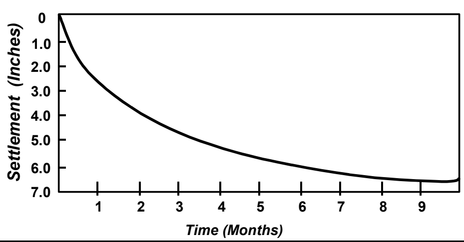
H_v = Vertical Drainage Path Length

C_V = Coefficient of Consolidation

Slide 6-1-19

Introduce and explain the time equation with emphasis on determination of the vertical drainage path and how this value may not be the same as the layer thickness.

Embankment on Clay Subsoil Time-Settlement Curve



Slide 6-1-20

Show the results of a typical time –settlement analysis and explain how to use this in project design. Mention that time for settlement is often over-predicted from the results of consolidation tests due unforeseen lateral drainage or disturbance of the test sample. Plant the seed for the use of instrumentation to measure the actual rate of consolidation during construction.

SOILS AND FOUNDATIONS WORKSHOP

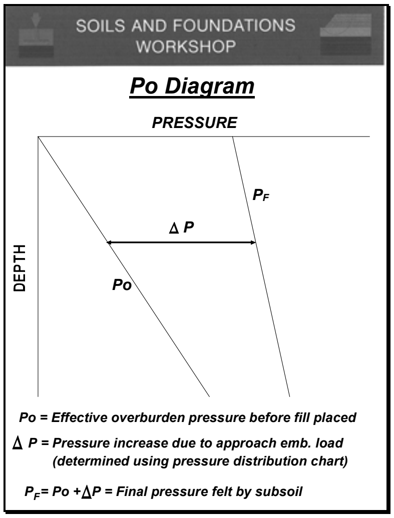
Estimate of Embankment Settlement Due to Consolidation of Subsoil

- ***Different computation methods for cohesive and cohesionless soils***
- ***Pressure distribution common to all soil types***

Slide 6-1-21

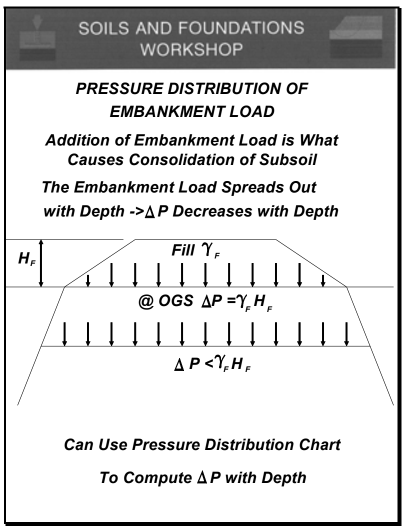
Instructor should use overhead transparencies for the remainder of this topic.

Explain that different computation methods are used for cohesive and granular soils but that pressure distribution is the same for both.



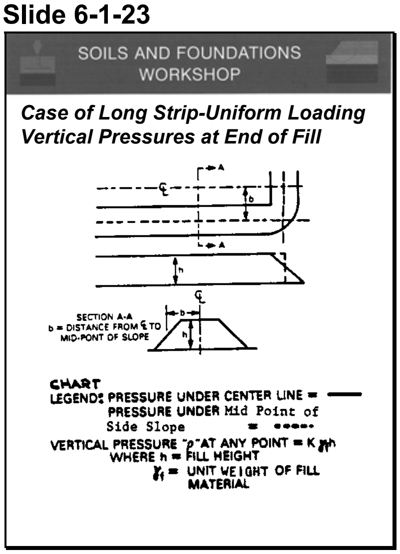
Slide 6-1-22

Show the Po diagram with an added entry of the distribution of pressure with depth. Important to state that pressure at various levels below ground is less than the pressure applied at the ground due to pressure distribution.



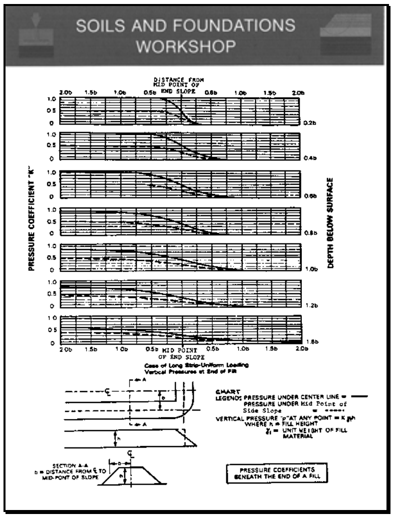
Slide 6-1-23

Stress that distribution depends only on the extent of the load area. The wider and longer the area of load; the greater the pressure at depth below ground. Note that discontinuities in loaded area (such at locations where the embankment stops and the bridge begins), can cause difficulties in finding how pressure is distributed with depth.



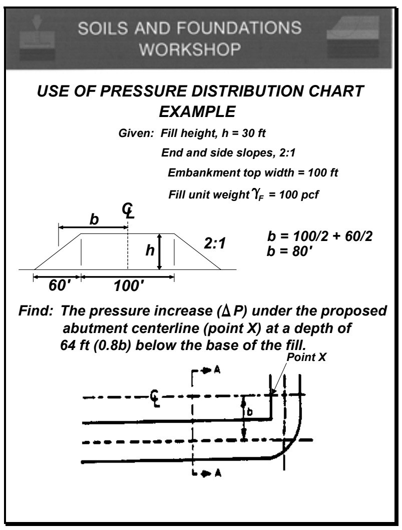
Slide 6-1-24

Until now, we have assumed only a condition where the fill is continuous in length. However in the case of end fills at bridges, the pressure distribution will be affected by the discontinuous fill. Pressures near the toe of fill are less than pressures beneath the top of fill. The term “b” which represents the half-width of the fill can be used to determine the variation of pressure both below ground and at distances along the length of the end fill.



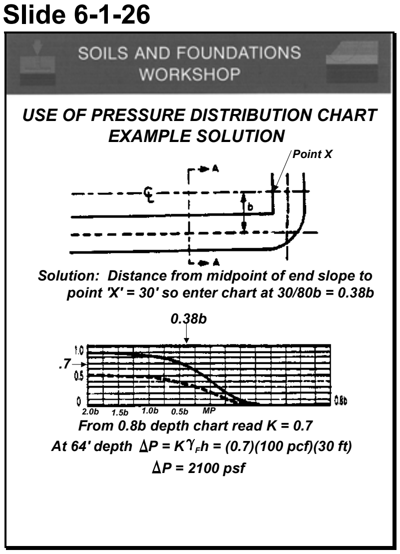
Slide 6-1-25

Show the end fill pressure distribution chart. This is the most difficult chart to grasp in the course and requires a slow, in-depth explanation; particularly of "b" which is the term which relates the extent of the loaded area to distribution.



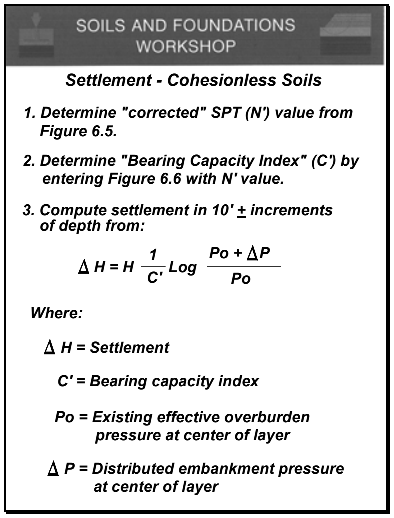
Slide 6-1-26

Explain the example with emphasis on the importance of the "b" term and how you computed the 'b' term. To be 80'. Then return to previous slide. Show students that the depth below ground can now be determined for each chart, (0.2b, 0.4b, etc.). Now the charts are for depth of 16', 32', 48', 64', etc. Then show next slide to illustrate the computation of 'k' at the 64' depth.



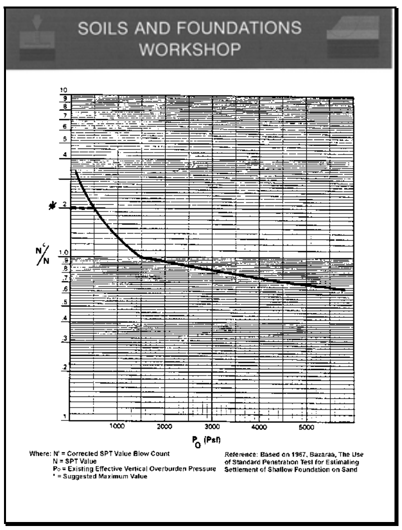
Slide 6-1-27

Explain the solution



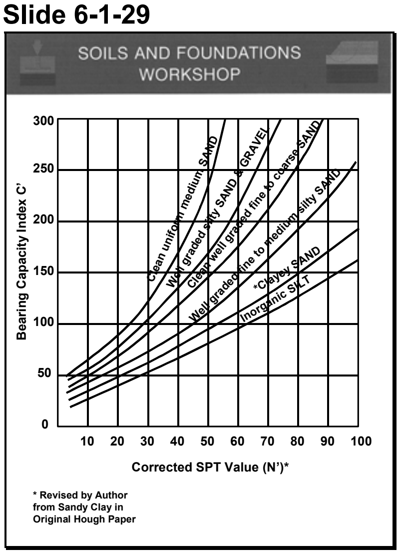
Slide 6-1-28

Overview the granular settlement computation process.



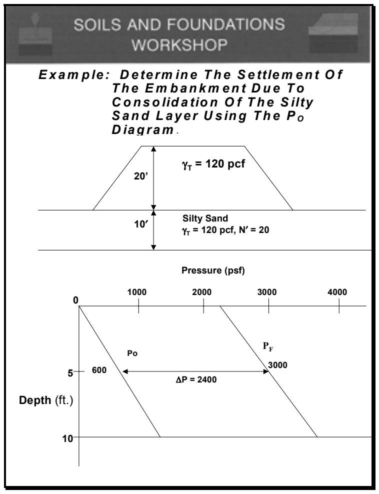
Slide 6-1-29

Explain why field N values need to be corrected.



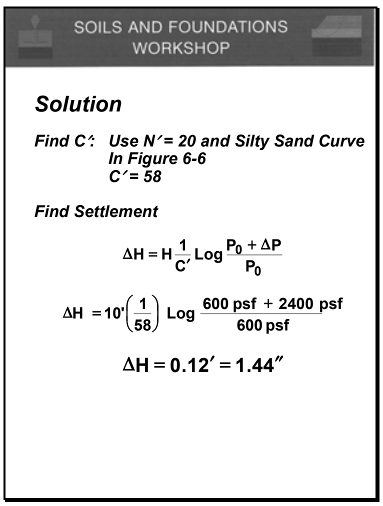
Slide 6-1-30

Explain how soil type affects compressibility. Remind Students of the relative volume solids and volume of voids for different soil types shown in lesson 4. Fine-grained soils consolidate more than coarse-grained soils. Note that original ASCE paper shows sandy clay but author probably meant to use clayey SAND.



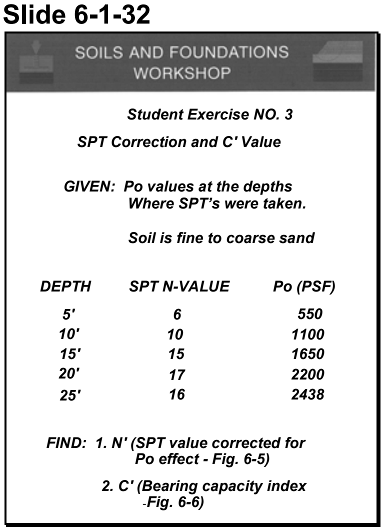
Slide 6-1-31

Instructor demonstrates granular settlement computational process in an example.



Slide 6-1-32

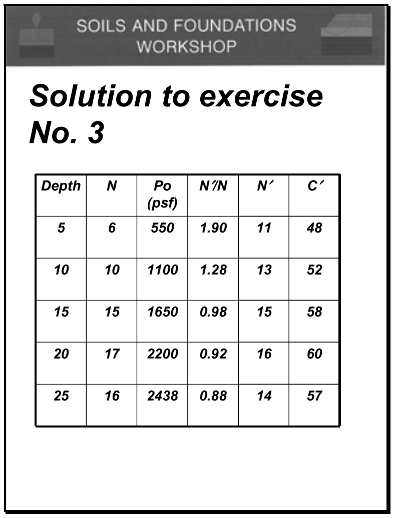
Instructor demonstrates granular settlement process in an example. Then go to the reference manual and point out where these figures are located.



Slide 6-1-33

Student exercise to find compressibility value for granular soils from both the field blow count and the soil visual from the lab. The purpose of the exercise is to show how the field value must be corrected for overburden pressure and the soil type identified before compressibility values can be found. The emphasis of the exercise is on the need to get quality input data for settlement analyses. The next example will extend the results into a settlement computation. After student exercise complete, ask for team to put results on flip chart or divide exercise into segments with team 1 computing only 5' depth values, team 2–10' values, etc. Then instructor asks teams for answers and write on flip chart. Ask team how results would have been affected if soil type were sand and gravel, or inorganic silt.

Please refer to the end of the lesson for this exercise.

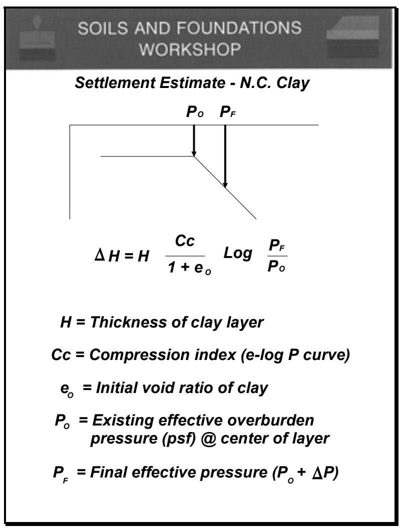


Depth	N	Po (psf)	N′/N	N′	C′
5	6	550	1.90	11	48
10	10	1100	1.28	13	52
15	15	1650	0.98	15	58
20	17	2200	0.92	16	60
25	16	2438	0.88	14	57

Slide 6-1-34

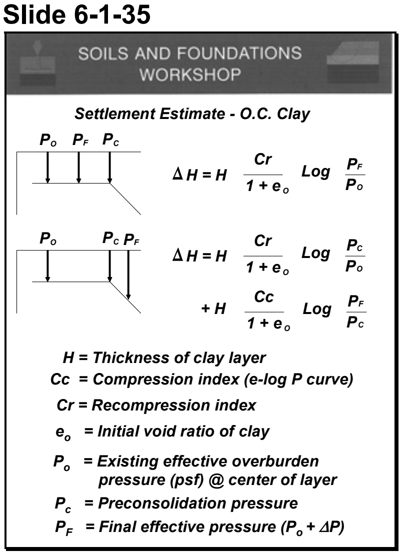
Show answers to student exercise.

Please refer to the end of the Participant Workbook for the solution to this exercise.



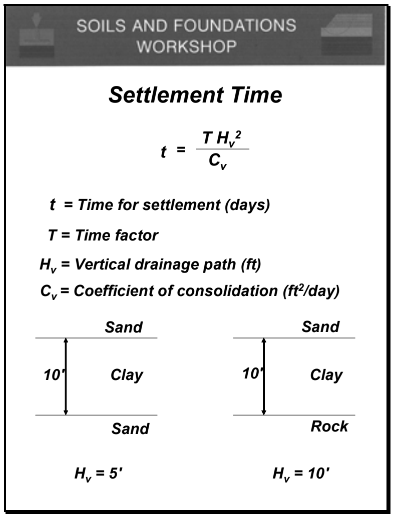
Slide 6-1-35

Introduce the computation of settlement in cohesive soils by starting with normally consolidated clays. Relate back to lab testing lesson on consolidation.



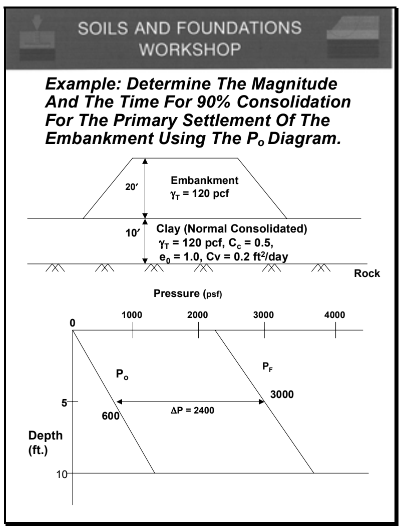
Slide 6-1-36

Discuss the method to estimate settlement in overconsolidated clays. Note that two computations may be necessary if the range of the change in pressure extends from P_o to above P_c.



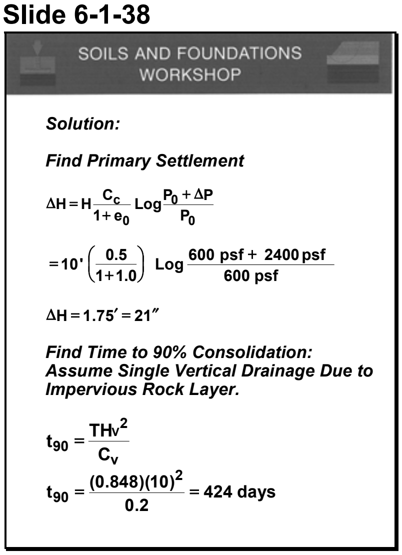
Slide 6-1-37

Introduce the computation for settlement time in clay soils. Then go to reference manual and review up to page 6-15.



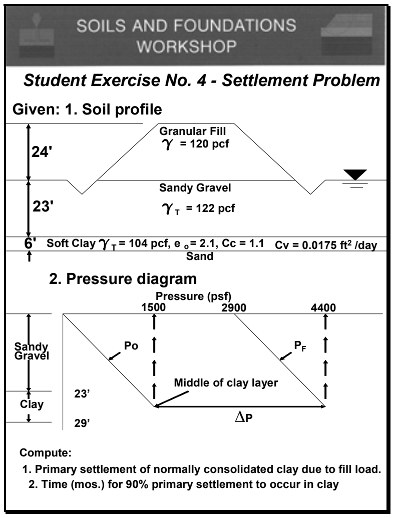
Slide 6-1-38

Demonstrate the computation process for clays. Build on the learned concepts from exercise on overburden pressure and the need for good consolidation data.



Slide 6-1-39

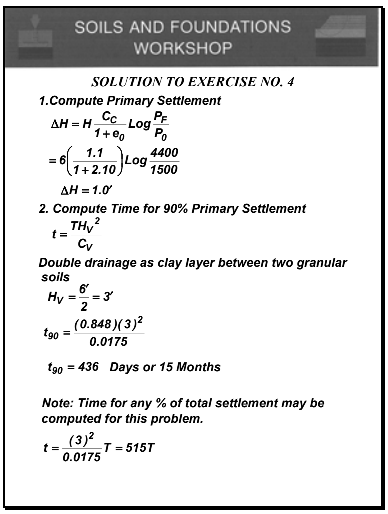
Instructor should solve this example by hand using a blank transparency. Show the solution to the clay settlement problem.



Slide 6-1-40

Student exercise on settlement in clay. The purpose of the exercise is to test learning of the settlement analysis process. The final question to the group after the analysis has been completed is "How accurate do you think this analysis is?" The answer is that depends on the quality of the data from the lab or the field. This recurring theme should be used in all exercises to continually reinforce the need for good data. Instructor demonstrates EMBANK software program. After student exercise, ask a team to put solution on the flip chart. Ask how time would be affected if the layer of clay were 12' thick?

Please refer to the end of the lesson for this exercise.

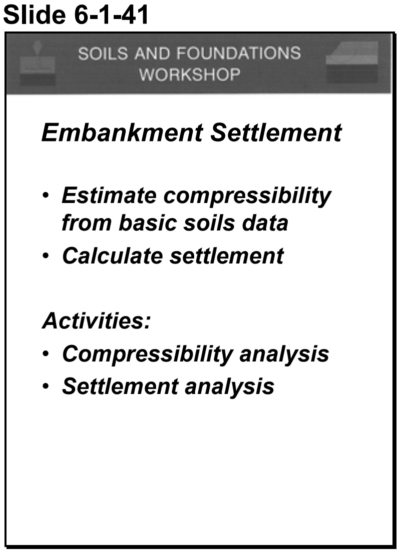


Slide 6-1-41

After student exercise, ask a team to put solution on the flip chart. Ask how time would affected if the layer of clay were 12' thick?

Instructor demonstrates EMBANK software program.

Please refer to the end of the Participant Workbook for the solution to this exercise.



Slide 6-1-42

Repeat objectives for lesson 6 topic 1.

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise NO. 3

SPT Correction and C' Value

GIVEN: Po values at the depths Where SPT's were taken.

Soil is fine to coarse sand

DEPTH	*SPT N-VALUE*	*Po (PSF)*
5'	6	550
10'	10	1100
15'	15	1650
20'	17	2200
25'	16	2438

FIND: 1. N' (SPT value corrected for Po effect - Fig. 6-5)

2. C' (Bearing capacity index -Fig. 6-6)

SOILS AND FOUNDATIONS WORKSHOP

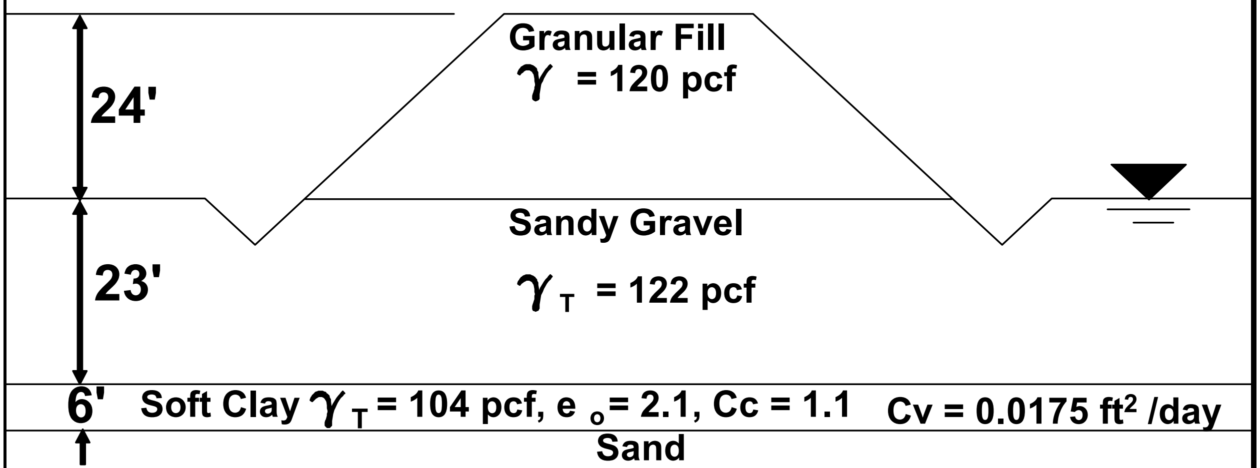
Solution to exercise No. 3

Depth	N	Po (psf)	N′/N	N′	C′
5	6	550	1.90	11	48
10	10	1100	1.28	13	52
15	15	1650	0.98	15	58
20	17	2200	0.92	16	60
25	16	2438	0.88	14	57

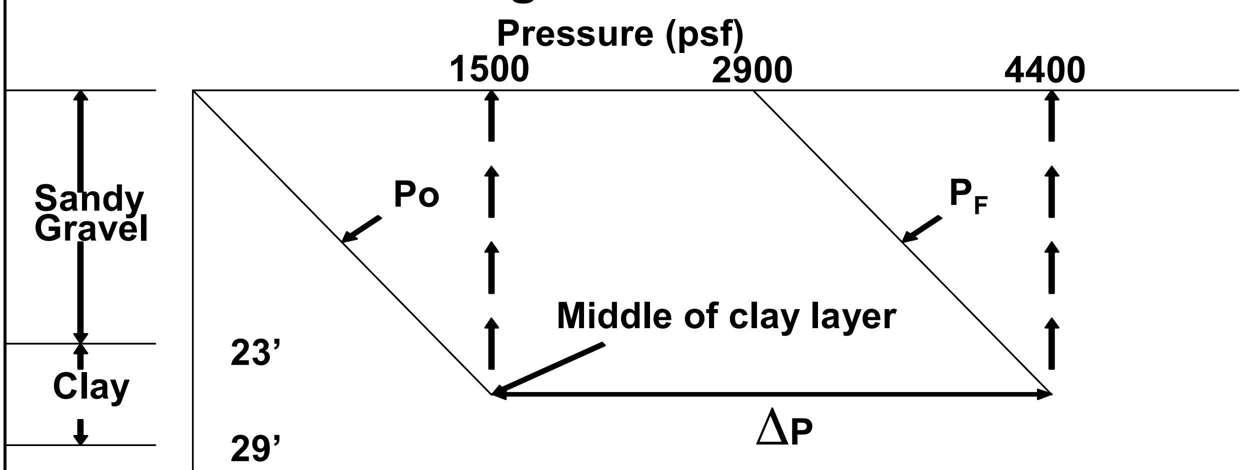
SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 4 - Settlement Problem

Given: 1. Soil profile



2. Pressure diagram



Compute:

1. Primary settlement of normally consolidated clay due to fill load.
2. Time (mos.) for 90% primary settlement to occur in clay

SOILS AND FOUNDATIONS WORKSHOP

SOLUTION TO EXERCISE NO. 4

1.Compute Primary Settlement

$$\Delta H = H \frac{C_C}{1+e_0} Log \frac{P_F}{P_0}$$

$$= 6\left(\frac{1.1}{1+2.10}\right) Log \frac{4400}{1500}$$

$$\Delta H = 1.0'$$

2. Compute Time for 90% Primary Settlement

$$t = \frac{TH_V{}^2}{C_V}$$

Double drainage as clay layer between two granular soils

$$H_V = \frac{6'}{2} = 3'$$

$$t_{90} = \frac{(0.848)(3)^2}{0.0175}$$

$$t_{90} = 436 \quad \text{Days or 15 Months}$$

Note: Time for any % of total settlement may be computed for this problem.

$$t = \frac{(3)^2}{0.0175} T = 515T$$

LESSON 6

TOPIC 2

Treatment for Embankment Settlement Problems

TREATMENT FOR EMBANKMENT SETTLEMENT PROBLEMS

Lesson 6 - Topic 2

Slide 6-2-1

Header

TREATMENT FOR EMBANKMENT SETTLEMENT PROBLEMS

1. Propose Solutions to Embankment Settlement Problems

ACTIVITIES: Question - Answer

Slide 6-2-2

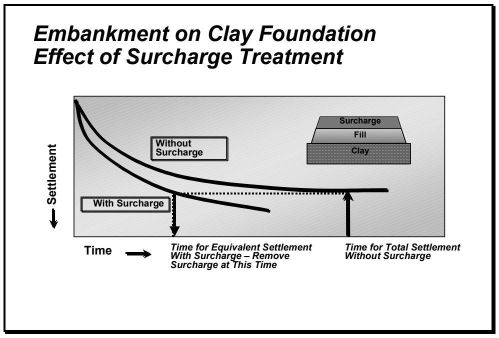
Objective

Solutions for Settlement Problems

- ***Reduce Settlement Amount***
  - ***Lower Grade***
  - ***Excavate and Replace Soft Soil***
  - ***Lightweight Fill***
- ***Reduce Settlement Time***
  - ***Surcharge***
  - ***Vertical Drains***

Slide 6-2-3

Introduce concepts of treatment for settlement.

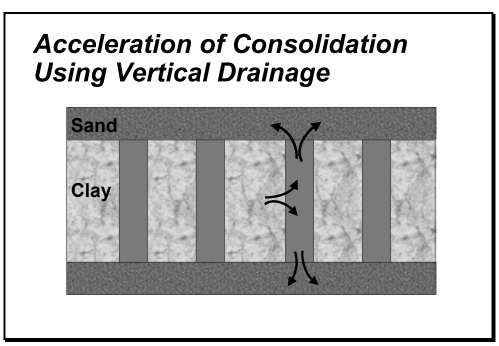


Slide 6-2-4

Explain the surcharge concept. Stress that the increased load placed on the soil does not change the drainage properties of the soil deposit. However a percentage of the total settlement will occur within a given time frame for a given soil deposit. Therefore if an increased load is applied, an amount of settlement equal to the settlement under the original load will occur in a shorter time. Note that a surcharge must be removed when the planned settlement has occurred.

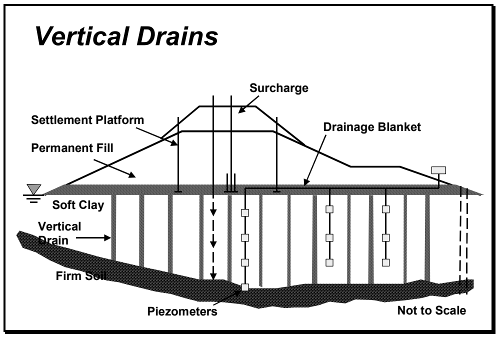
Slide 6-2-5

Surcharge case history. This is a surcharge placed on the Salt Lake City I-15 project. Note that the lateral extent of the surcharge was maximized by using a soil reinforcement system to build the surcharge with a vertical face. Also note that a relatively high embankment was being surcharged at this location. The design attempted to maximize the surcharge height as the relative proportion of surcharge load was small compared to the total embankment load.



Slide 6-2-6

Show vertical drain concept. Note that drains are most effective for wide embankments over deep clay layers. Explain the process of first constructing a permeable drainage layer over the original ground to allow the discharge to flow out to the sides of the fill. The spacing is designed based on the type of drain and the soil properties. The drains are installed by a variety of equipment depending on drain type and soil conditions. The water flow from the drains is caused by the pressure induced in the pore water by the embankment load.



Slide 6-2-7

Show typical cross section of vertical drain installation. Mention the use of instrumentation to monitor the actual rate of consolidation of the soil deposit. Remind students that settlement is primarily caused by squeezing water out of the soil deposit.

Slide 6-2-8

Show example of soil type suitable for vertical drainage then use a sequence of slides to demonstrate how a typical drain project would proceed and options available for drain types.

Slide 6-2-9

Drainage blanket placement.

Vertical Drain Installation Sequence

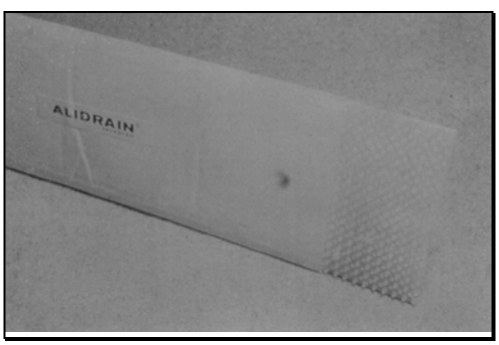
- *Position Rig at Drain Location*
- *Place Anchor on Drain End*
- *Penetrate Mandrel to Desired Depth*
- *Withdraw Mandrel*
- *Cut Drain Material Above Drainage Blanket*

Slide 6-2-10

Overview sequence of prefabricated drain installation prior to showing a series of slides of the actual construction operations.

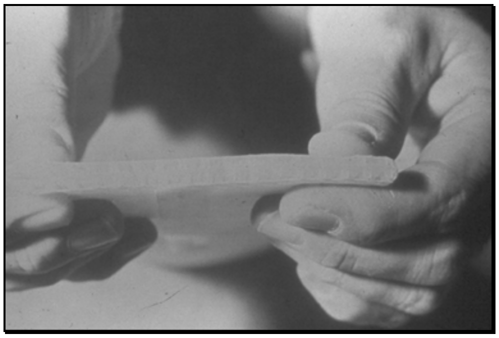
Slide 6-2-11

Prefabricated drain material have virtually replaced sand drains in recent years. The material is relatively inexpensive and the installation process rapid. The drain material is manufactured in rolls as shown here.



Slide 6-2-12

Typical prefabricated drain which has a plastic corrugated core to allow water flow up the drain and a filter fabric jacket to prevent fines from entering the drain. Typical drain width is about 4”.


Slide 6-2-13

Prefabricated drain thickness generally vary from 0.1” to ¼”.


Slide 6-2-14

Drain installation equipment.


Slide 6-2-15

The mandrel and the end anchor are shown for the prefabricated drain. Note that manufacturers have tried to limit the cross sectional area of the mandrel and drain to reduce displacement and resulting soil disturbance which reduces flow to the drain.

Slide 6-2-16

Mandrel fully inserted.

Slide 6-2-17

Mandrel withdrawn with drain ready for trim.

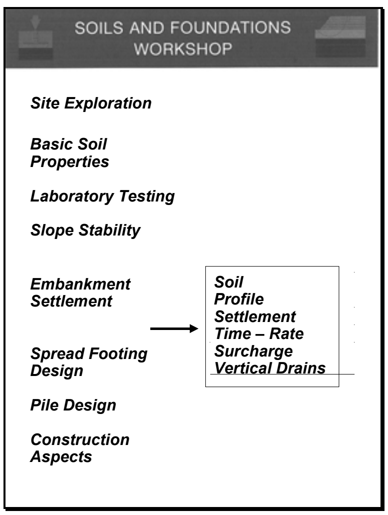
Slide 6-2-18

Final in place prefabricated drain. Note that prefabricated drain can be placed at average rates of 40' per minute depending on conditions. Length of drain may be limited by the equipment as the mandrels tend to be relatively thin and flexible. Also compact surface deposits may need to be pre-augered to allow mandrel penetration.


Slide 6-2-19

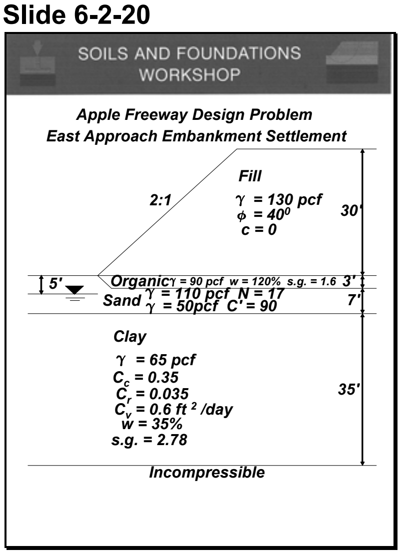
Final installation, note close drain spacing.

After slides, pass around a sample of a wick drain.



Slide 6-2-20

Summary of progress on Apple Freeway design problem.

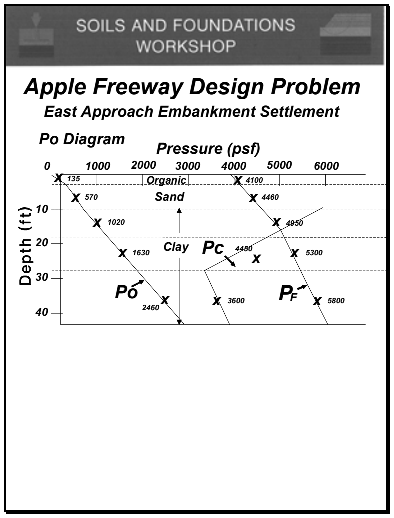


Slide 6-2-21

Show Apple Freeway soil profile for the East approach.

Ask students which layer will settle the most.

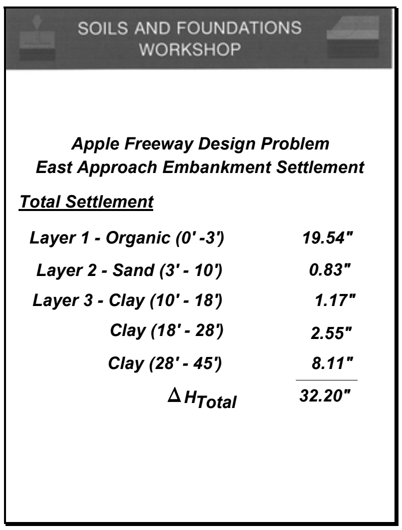
Ask the students to explain the process for calculating the settlement.



Slide 6-2-22

Ask how preconsolidation impacts settlement amount.

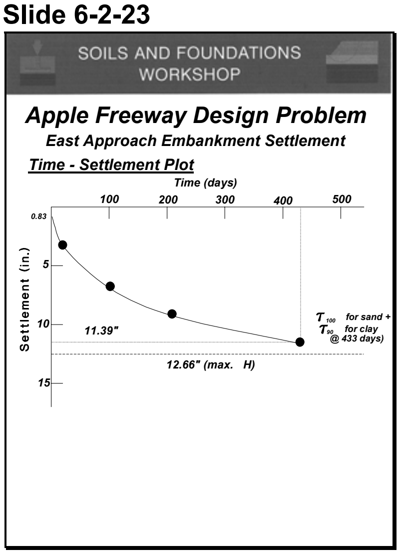
Answer: Reduces amount



Slide 6-2-23

Ask the best method to use to cheaply reduce the settlement.

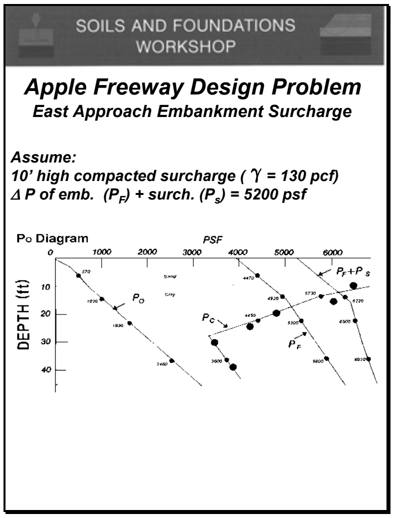
Answer: Excavate organic soil.



Slide 6-2-24

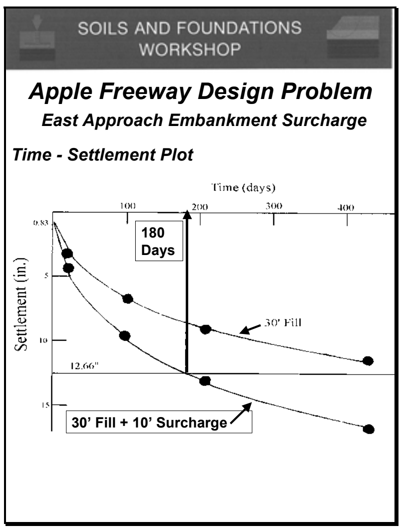
Show results of time settlement and ask how settlement amount or time can be further reduced.

Answer: Excavate soft soil, lightweight fill, surcharge, or vertical drains. Note lowering grade not an option due to clearance requirements over Apple freeway.



Slide 6-2-25

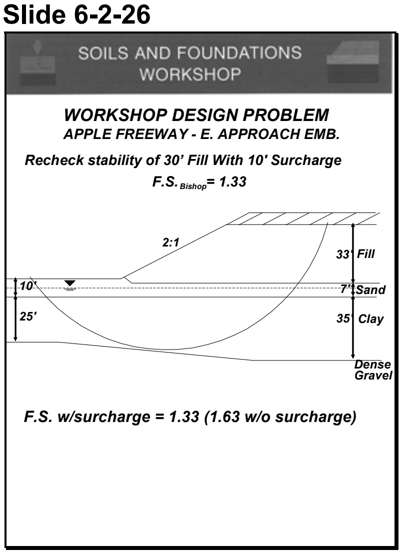
Show surcharge design.



Slide 6-2-26

After showing this two-overhead sequence, the instructor asks what else needs to be checked in design prior to approving the use of a surcharge.

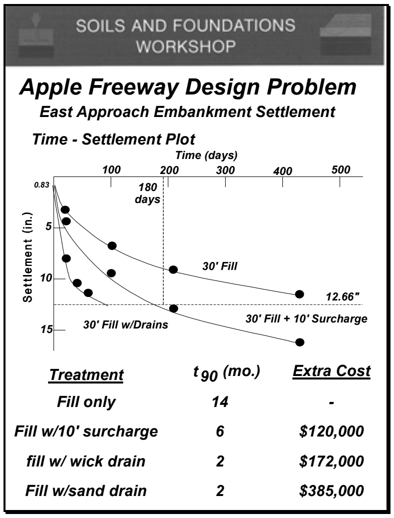
Answer: Stability of embankment plus surcharge.



Slide 6-2-27

Ask if safety factor is ok.

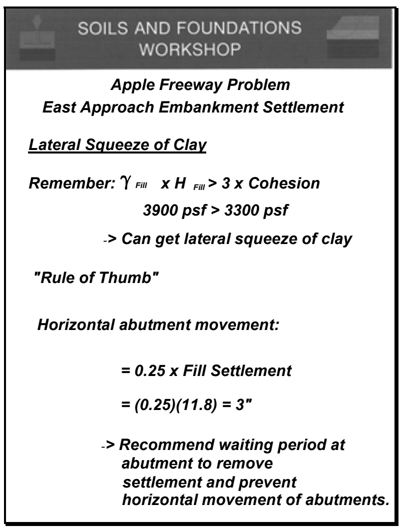
Answer: Yes.



Slide 6-2-28

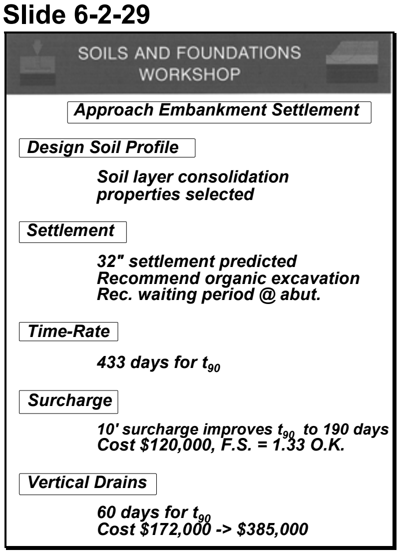
Show Apple Freeway summary for decision making by management. Then ask if we need to check anything else.

Answer: Lateral squeeze



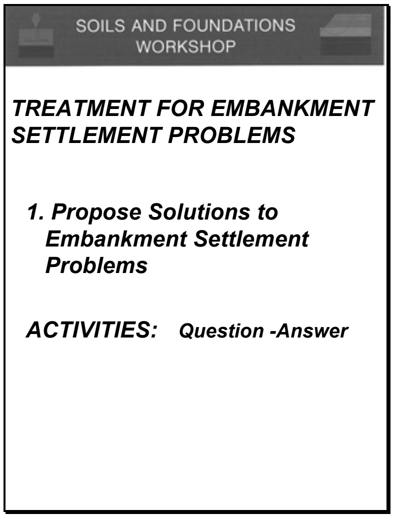
Slide 6-2-29

Show lateral squeeze issue.



Slide 6-2-30

Summarize status of Apple Freeway design



Slide 6-2-31

Review objectives from beginning of class.

Note that the first two project phases have been completed; data gathering and embankment design. Now structural design can begin.

LESSON 7

TOPIC 1

Spread Footing Design – Bearing Capacity

Structural Foundation Topics

- *Shallow Foundations (Spread Footings)*
  - *Bearing Capacity*
  - *Settlement*
- *Deep Foundations*
  - *Load Capacity*
  - *Settlement*
  - *Negative Skin Friction*

Slide 7-1-1

Review flip chart sheets, which are around room to update class on status of geotechnical process and status of their learning.

Introduce the structural topics to be considered in the upcoming lessons. Note again that the data gathering and embankment work must be complete before this work begins.

SPREAD FOOTING DESIGN

Lesson 7 - Topic 1
Bearing Capacity

Slide 7-1-2

Header slide

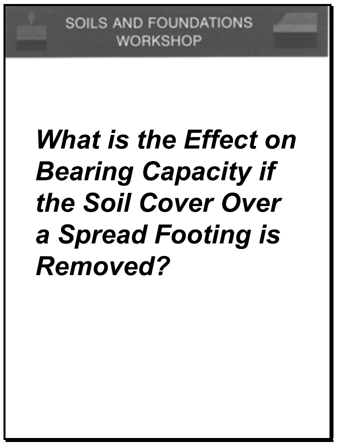
SPREAD FOOTING DESIGN
Bearing Capacity

1. Explain How Footing Embedment, Width and Water Table Effect Footing Bearing Capacity

ACTIVITY: Bearing Capacity Analysis

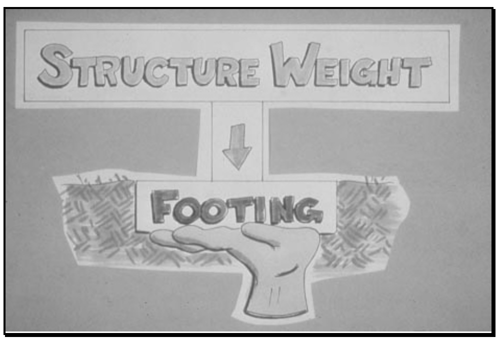
Slide 7-1-3

Objectives



Slide 7-1-4

Show and ask for opinion before showing slides.

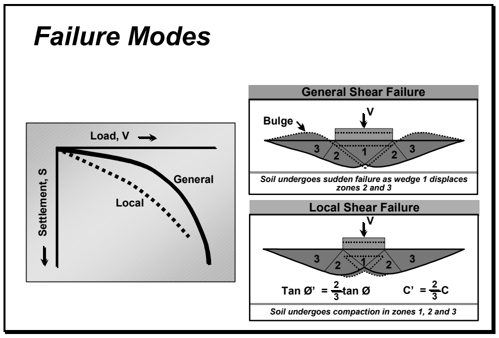


Slide 7-1-5

Show schematic. Emphasize that a spread footing is a structural element that is sized to apply no more than the allowable pressure to the foundation soil.

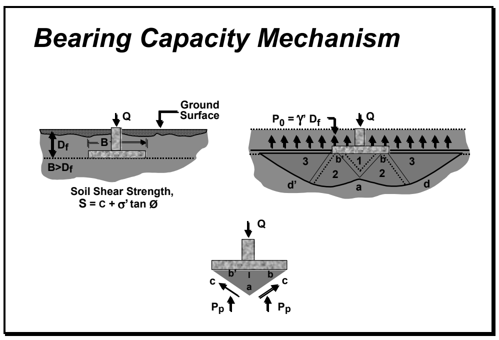
Slide 7-1-6

Show failure case history. Begin humorously stating that "this designer did not have a good idea about what is important in the bearing capacity of spread footing". The failure actually occurred due to scour at river crossing. However do not explain how failure occurred but return to this slide later after the audience has learned the basics of bearing capacity.



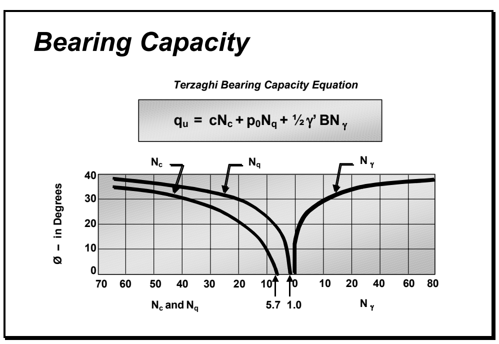
Slide 7-1-7

Explain both failure mechanisms and why only the general shear failure is considered for highway bridge footings. Begin with a description of the load vs. settlement plot and describe both failures. Then describe in detail how the general shear failure occurs with sequential movement of wedges 1-3 as the load on the footing is increased. Do the same for the local shear failure. Note that local shear failure is common for soft soils and for small footings but highway agencies who routinely take borings at all bridge site do not place footings on soft soils and therefore do not worry about local failure.



Slide 7-1-8

Focus on practical aspects of failure so students see how footing size, soil friction angle and embedment impact capacity. Explain progression of failure from wedge formation to uplift of zone 3 and surcharge.



Slide 7-1-9

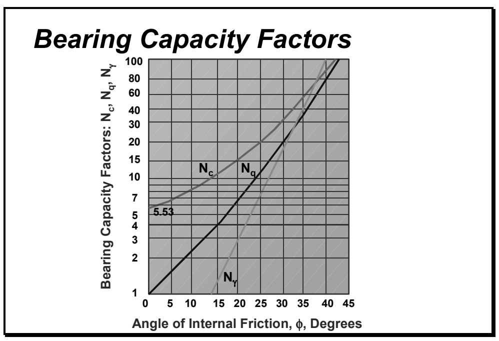
Show basic equation for bearing capacity. Ask student what the N terms reflect. (The answer is the geometry of the failure zone) Lead students to answer by comparing this analysis to the slope stability analysis. Note in slope stability that we multiplied cohesion times length of arc…then ask what the N_c term represents in the bearing capacity equation. Emphasize that theoretical meaning and formula for N terms not as important as physical meaning of terms. Restate how important the friction angle is for bearing capacity.

Bearing Capacity Equations

- **Terzaghi:**
  - $q_{ult} = cN_c + P_oN_q + 1/2\gamma BN_\gamma$
- **Brinch Hanson**
  - $q_{ult} = cN_c\, s_c d_c i_c + P_o N_q s_q d_q i_q + 1/2\gamma BN_\gamma s_\gamma d_\gamma i_\gamma$

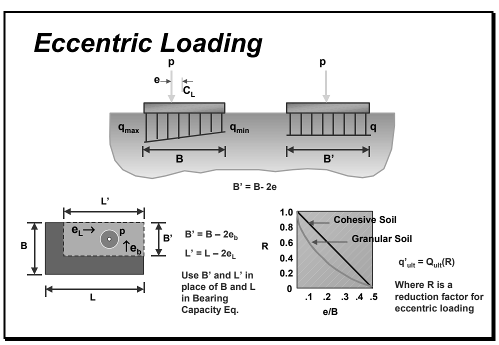
Slide 7-1-10

Explain that the basic equation has been modified to be more accurate but that the basic equation will be used in this class for learning of the concepts. Students are encouraged to use more complex formula in real project activities.



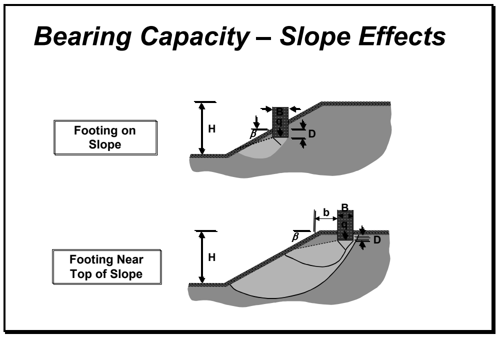
Slide 7-1-11

Explain the use of the bearing capacity factor chart and the corresponding equations. Note that many different charts of bearing capacity factors have been published by authors. In this class a chart developed by Meyerhof and published in other Federal documents will be used.



Slide 7-1-12

Show that different types of analyses can be done for inclined footings, footings in slopes or abutment type footings. These are beyond the scope of the class.



Slide 7-1-13

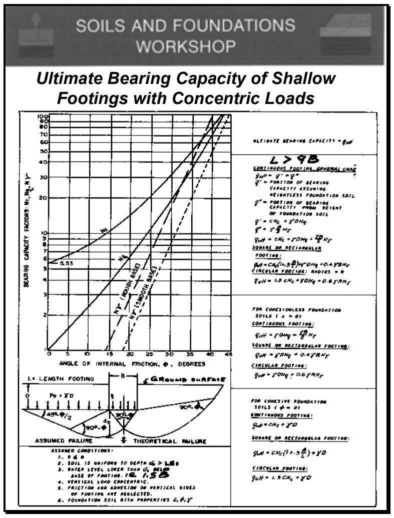
Show that different types of analyses can be done for inclined footings, footings in slopes or abutment type footings. Ask the class what is different about the computation of bearing capacity on slopes from that on level ground. (This question seldom results in the correct answers of "different bearing capacity factors as the geometry is different" without some coaching but makes student think about the process). These are beyond the scope of the class.

Slide 7-1-14

Emphasize that an advantage of spread footings is the uncovering of the soil, which will support the footing loads. The inspector can easily verify the soil type and compactness prior to footing construction.

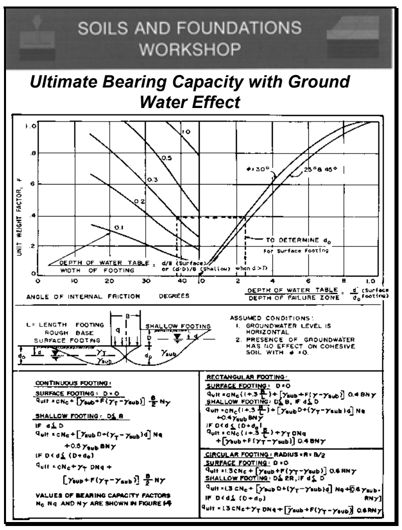
Slide 7-1-15

Case history of what happens when the excavation uncovers unexpected soil conditions and a good lesson to reinforce the need for an adequate site investigation. This retaining wall project was located in an urban area where the homes were very closely spaced. All borings were taken between the homes previous to demolition of the homes. No one reported that homes with basements were located at the site and the designer never visited the site. The designer relied completely on the boring logs which showed dense granular soil and no water table. The design selected was a spread footing for the retaining wall, which extended across the demolished home basements. The bad news is the site investigation was inadequate but at least the inspector recognized the problem during initial excavation of the wall footings and called for a redesign.



Slide 7-1-16

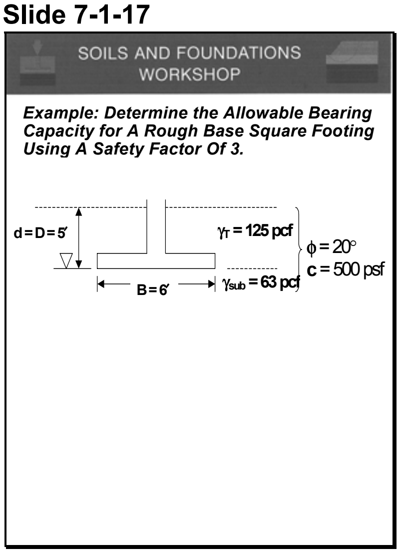
Explain in detail the use of the figure and the limitations of the figure (concentric loads, no water table in the failure zone, and level ground). Note that the frictional bearing capacity factors are shown as either rough (concrete or wood) or smooth (steel or plastic) as the contact surface of the footing base affect capacity. Also note that the equations shown are for continuous and rectangular footing shapes. A rectangular footing equation is used when the footing length is 9 times the footing width or less.



Slide 7-1-17

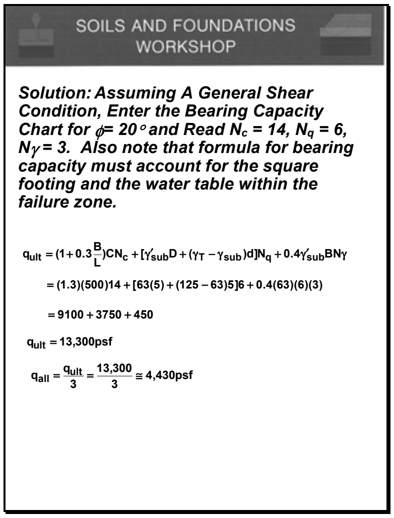
Explain how water affects the various terms in the bearing capacity equation. Explain why the correction is not as simple as dividing by 2. (Relate the amount of soil made buoyant in the failure zone by use of a simile to a bowl of cereal being slowly filled with milk, the amount of cereal that is covered with milk is very small at the base of the bowl but very large when the top of the bowl is reached. A small intrusion of water into the failure zone has a negligible effect but as the water rises the volume of buoyant soil increases rapidly and the capacity decreases).

Go to the reference manual and overview the bearing capacity sections including the charts just presented.



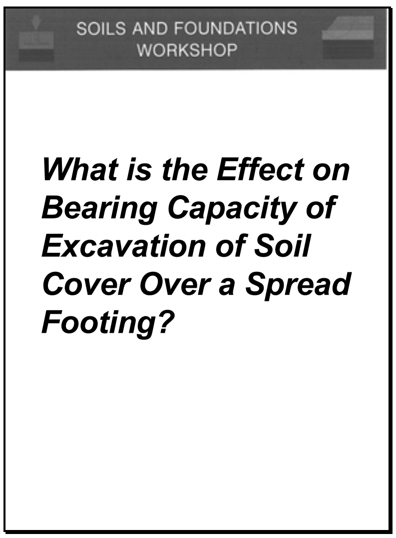
Slide 7-1-18

Instructor should go to Reference Manual before explaining the example. Demonstrate the computational process by example.



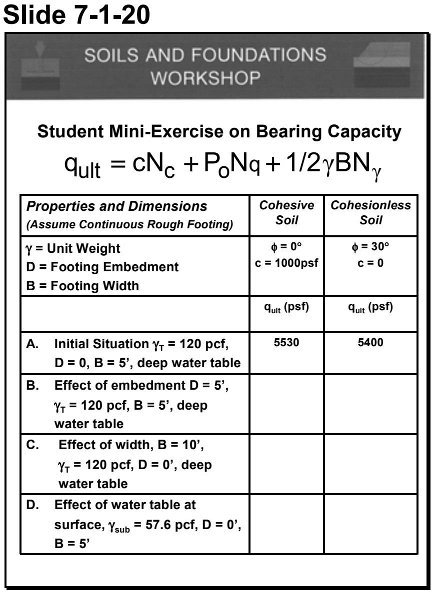
Slide 7-1-19

Demonstrate the computational process by example



Slide 7-1-20

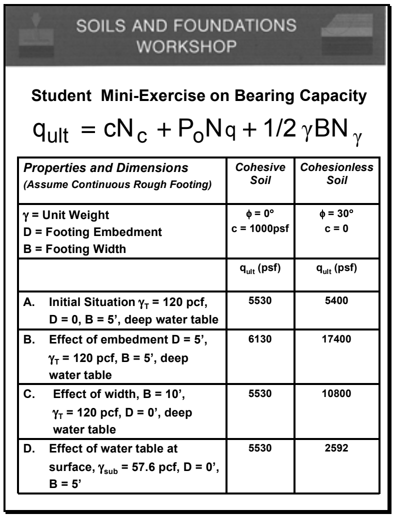
Ask the question and how one would quantify the impact.



Slide 7-1-21

The mini-exercise in the participant manual has blanks in all columns except the first row initial situation. The idea is to familiarize the students with the bearing capacity chart before giving them a student exercise. Assign each table a different cell to complete and then ask for responses to fill in the answers on a flip chart. After completing the chart, refer back to the first slide in the presentation of the failed pier. This pier was placed on spread footings in a flood plain and designed for 6000 lbs/ft^2 (about 19,000 ultimate). When ground water rose to ground surface, ultimate capacity drop to 9,500 psf. When floodwater eroded soil cover the ultimate capacity dropped below the design value and failure occurred. Instructor asks the students to study and remember the impact of each change (b, c, & d) on the bearing capacity for both cohesive and cohesionless soils.

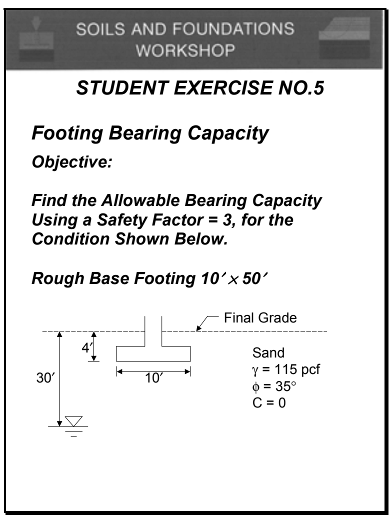
Please refer to the end of the lesson for a full size version of this slide.



Slide 7-1-22

The mini-exercise in the participant manual has blanks in all columns except the first row initial situation. The idea is to familiarize the students with the bearing capacity chart before giving them a student exercise. Assign each table a different cell to complete and then ask for responses to fill in the answers on a flip chart. After completing the chart, refer back to the first slide in the presentation of the failed pier. This pier was placed on spread footings in a flood plain and designed for 6000 lbs/ft^2 (about 19,000 ultimate). When ground water rose to ground surface, ultimate capacity drop to 9,500 psf. When floodwater eroded soil cover the ultimate capacity dropped below the design value and failure occurred. Instructor asks the students to study and remember the impact of each change (b, c, & d) on the bearing capacity for both cohesive and cohesionless soils.

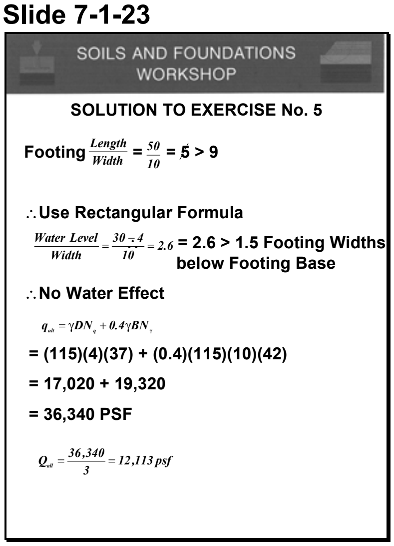
Please refer to the end of the lesson for a full size version of this slide.



Slide 7-1-23

After exercise chose team to put solution on flip chart. Ask team about the magnitude of the bearing capacity and what value should be used in future settlement computations. Student exercise is used to test knowledge of computational process for bearing capacity of spread footings. Exercise requires basic judgment about which equation and which bearing capacity chart should be used. The instructor should ask the team who explains the answer to evaluate if the answer is realistic. The answer is yes assuming the data used is correct.

Please refer to the end of the lesson for this exercise.

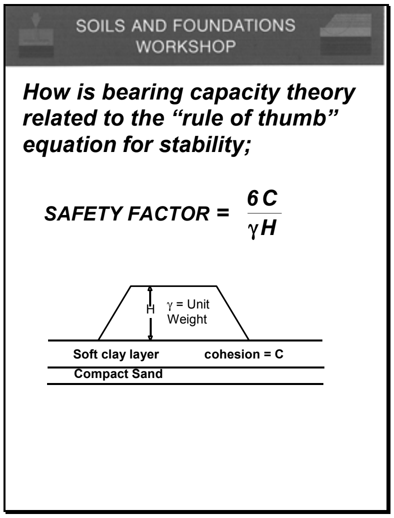


Slide 7-1-24

After students explain the solution on the flip chart. Instructor should ask a question concerning the analysis such as, “is the allowable bearing pressure realistic for this situation?” (Answer is yes)

But, pressure is so large that the designer may not be able to take advantage of the full amount.

Please refer to the end of the Participant Workbook for the solution to this exercise.



Slide 7-1-25

Ask students where the rule of thumb came from?

Slide 7-1-26

Repeat objectives for lesson 7 topic 1.

SOILS AND FOUNDATIONS WORKSHOP

Student Mini-Exercise on Bearing Capacity

$$q_{ult} = cN_c + P_o N_q + 1/2 \gamma B N_\gamma$$

Properties and Dimensions *(Assume Continuous Rough Footing)*	***Cohesive Soil***	***Cohesionless Soil***
γ = Unit Weight **D = Footing Embedment** **B = Footing Width**	**$\phi = 0°$** **c = 1000psf**	**$\phi = 30°$** **c = 0**
	q_{ult} (psf)	**q_{ult} (psf)**
A. Initial Situation γ_T = 120 pcf, D = 0, B = 5', deep water table	**5530**	**5400**
B. Effect of embedment D = 5', γ_T = 120 pcf, B = 5', deep water table		
C. Effect of width, B = 10', γ_T = 120 pcf, D = 0', deep water table		
D. Effect of water table at surface, γ_{sub} = 57.6 pcf, D = 0', B = 5'		

SOILS AND FOUNDATIONS WORKSHOP

Student Mini-Exercise on Bearing Capacity

$$q_{ult} = cN_c + P_oN_q + 1/2\,\gamma B N_\gamma$$

Properties and Dimensions *(Assume Continuous Rough Footing)*	***Cohesive Soil***	***Cohesionless Soil***
γ = Unit Weight **D = Footing Embedment** **B = Footing Width**	**$\phi = 0°$** **c = 1000psf**	**$\phi = 30°$** **c = 0**
	q_{ult} (psf)	**q_{ult} (psf)**
A. Initial Situation γ_T = 120 pcf, D = 0, B = 5', deep water table	**5530**	**5400**
B. Effect of embedment D = 5', γ_T = 120 pcf, B = 5', deep water table	**6130**	**17400**
C. Effect of width, B = 10', γ_T = 120 pcf, D = 0', deep water table	**5530**	**10800**
D. Effect of water table at surface, γ_{sub} = 57.6 pcf, D = 0', B = 5'	**5530**	**2592**

SOILS AND FOUNDATIONS WORKSHOP

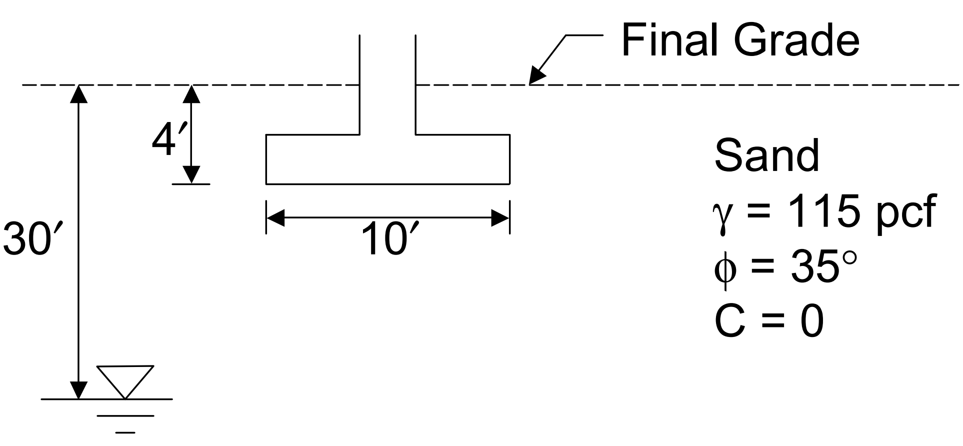
STUDENT EXERCISE NO.5

Footing Bearing Capacity

Objective:

Find the Allowable Bearing Capacity Using a Safety Factor = 3, for the Condition Shown Below.

Rough Base Footing 10′ × 50′



SOILS AND FOUNDATIONS WORKSHOP

SOLUTION TO EXERCISE No. 5

Footing $\frac{Length}{Width} = \frac{50}{10} = \not{5} > 9$

∴ Use Rectangular Formula

$\frac{Water\ Level}{Width} = \frac{30 - 4}{10} = 2.6$ **= 2.6 > 1.5 Footing Widths below Footing Base**

∴ No Water Effect

$$q_{ult} = \gamma D N_q + 0.4 \gamma B N_\gamma$$

= (115)(4)(37) + (0.4)(115)(10)(42)

= 17,020 + 19,320

= 36,340 PSF

$$Q_{all} = \frac{36,340}{3} = 12,113\ psf$$

LESSON 7

TOPIC 2

Spread Footing Design - Settlement

SPREAD FOOTING DESIGN

Lesson 7 - Topic 2
Settlement

Slide 7-2-1

Header

SPREAD FOOTING DESIGN
Settlement

1. Perform Settlement Analysis in Cohesive and Granular Soil
2. Name Solutions to Reduce Settlement Amount or Time

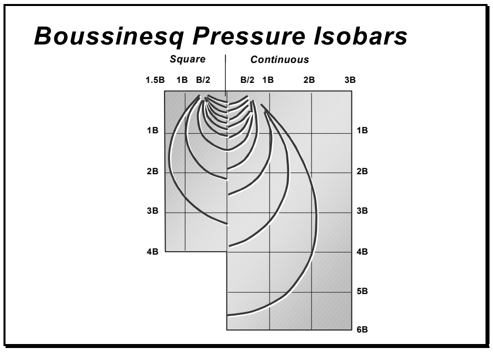
ACTIVITY: Settlement Analysis

Slide 7-2-2

Objective

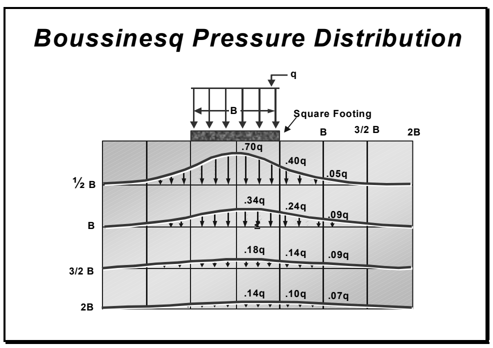
Slide 7-2-3

Case history of settlement of bridge abutment at site where no borings were taken. This bridge was placed on spread footings at a site where no borings were taken and the design was done to “match the design of a bridge down the road as the soils in this area are all the same”. Note that a large shim has been produced under the bearing plate because of continuing settlement of the bridge. The maintenance problem was so bad that a boring was taken at the location to find out what soils existed. The boring found a shallow layer of sand underlain by a thick layer of soft soil. Subsequent settlement analyses indicated that over a foot of additional settlement could be expected over a 10 year period.



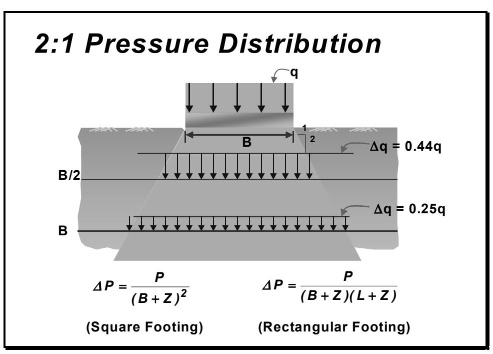
Slide 7-2-4

Re-emphasize that size of loaded area controls pressure distribution. Note difference in the penetration of pressure with depth between square and continuous footing of same width.



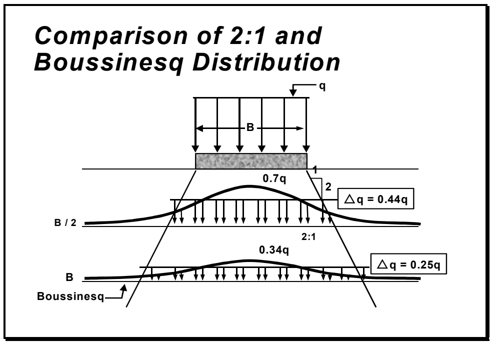
Slide 7-2-5

Explain the Boussinesq concept of pressure distribution.



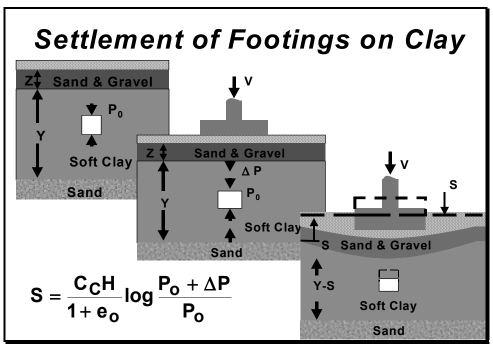
Slide 7-2-6

Explain the simplified concept of 2 to 1 distributions.



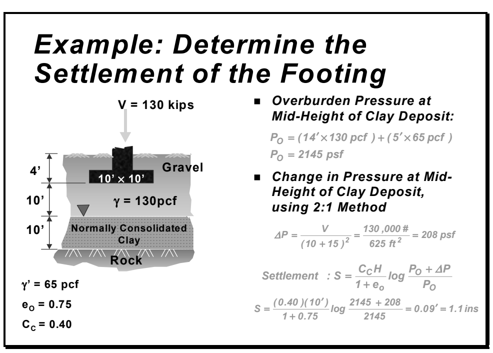
Slide 7-2-7

Compare both methods and use the simpler method for teaching.



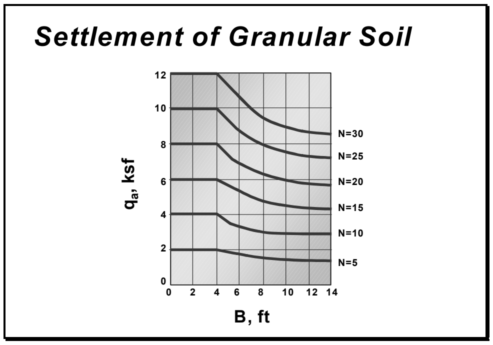
Slide 7-2-8

Review the concept of settlement of cohesive soils.



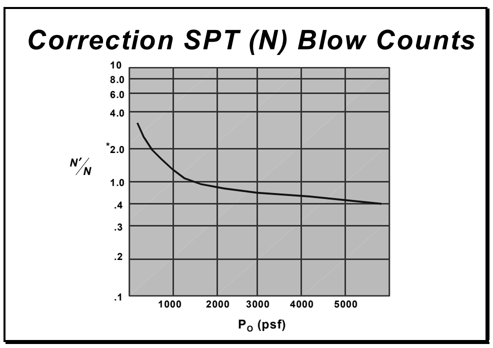
Slide 7-2-9

Apply the concept in an example to illustrate the computational process.



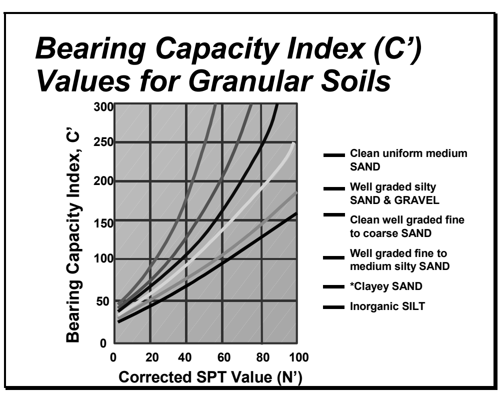
Slide 7-2-10

Show a simplistic chart for settlement estimation in granular soils that gives the allowable bearing pressure which will cause less than 1” of settlement. Ask what are the problems with this chart (answer is that the chart is overly simplistic and was developed on very limited case history information that was concentrated in small footing sizes and moderate bearing pressures. Higher bearing pressures have resulted in unconservative predictions of footing settlement). Then show the next two slides, which contain the correct process.



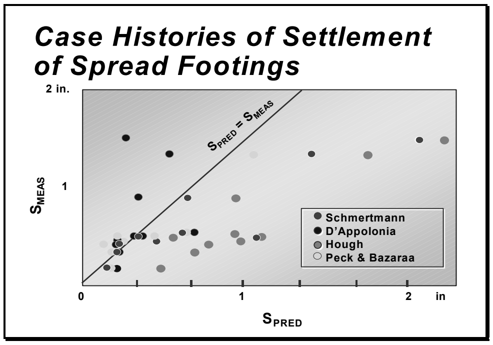
Slide 7-2-11

The correct procedure, as previously discussed, first involves correction of SPT blows for overburden pressure.



Slide 7-2-12

The second step is to consider the granular soil type to find the compressibility. And then use the actual distributed pressure and previous settlement equation to find the settlement.

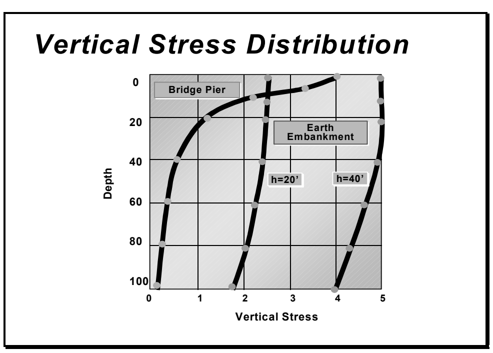


Slide 7-2-13

Show the results of research on the current settlement method and explain how the method is conservative. Note the original publication is discussed on page 7-14 of the reference manual Recommend other methods in other FHWA publications for project work.

Slide 7-2-14

Contrast the amount of load applied to the soil at the location of the abutment to the load applied at the pier. The settlement of soils beneath the abutment is caused by the weight of fill more than the small abutment load. The lesson learned is that we need to take care of the embankment settlement before considering the use of spread footings at the abutment.



Slide 7-2-15

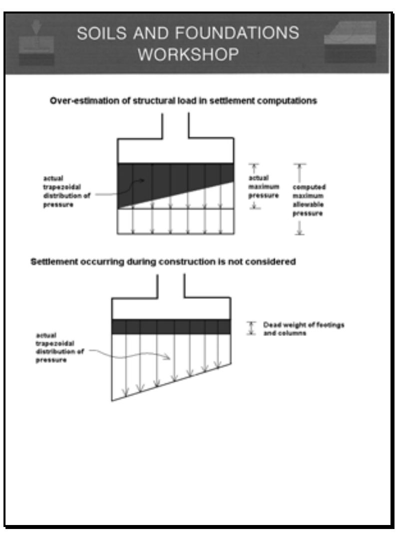
Compare the differences in pressure distribution for a pier and an embankment and ask the group why the great difference (the answer is that the width of the embankment is much greater than the structure footing and therefore the pressure extends to greater depths).

Slide 7-2-16

Case history of large settlement causing structural problems at an abutment. In this case the high approach fill was constructed over very soft compressible soils without any attempt to mitigate the settlement. Then the piles were immediately driven for the bridge and the structure built as quickly as possible. The 6’ of approach embankment settlement that subsequently occurred in the following months resulted in severe damage to the structure including shearing off the piles under the abutment. Also the water and gas mains were severed that were carried under the bridge structure and through the backwall. The important point is that the weight of the embankment is very large and when downward movement begins, the force will shear off the foundations.

Slide 7-2-17

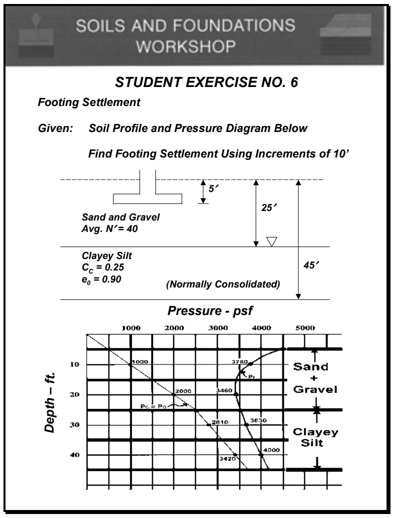
Case history to demonstrate that piers in end fills can be subject to tilting if the differential settlement is not accounted for. Note that the rock fill is 80’ high and the end slope constructed on a 1 to 1 slope. The proposed 80’ high pier column with a 24’ wide footing, which is in the end slope, has been built in the two stages with the first stage shown. Ask the group why the designer chose this method of construction. The answer is because of the last job when the pier columns titled toward the fill and the beams id not fit. This is due to the 24’ of differential fill height that is over opposite ends of the 24’ wide pier footing.



Slide 7-2-18

Explain why communication with structure's office can improve settlement prediction by geotechnical engineers. Remind the audience that the settlement computation commonly occurs long before the structure design is finalized. Focus on the three aspects shown here; the lack of knowledge of both the actual magnitude and distribution of the footing load and the fact that most granular soil settlement occurs during construction. In the absence of information geotechnical engineers tend to assume the maximum allowable bearing pressure will be used by the structural designer. This is usually an erroneous assumption that will lead to computation of unrealistic settlement for the footing.

At this point go to the reference manual and cover the important items that were shown in the slides with emphasis on the sections that show how settlement is computed. Then ask if everybody is ready to calculate footing settlement and show the student exercise.



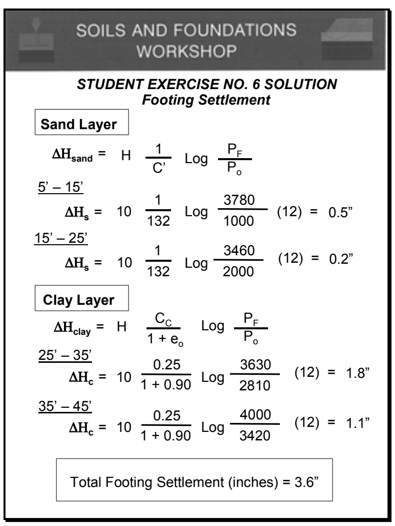
Slide 7-2-19

Instructor should use overhead transparencies for the remainder of this topic.

Student exercise on settlement of spread footings. Purpose is to test learning of the computational process and reinforce concepts of pressure distribution and need for good data. Ask students to do exercise by using 10' depth increments as shown in the profile for each soil layer. This will involve 4 computations to get to the total settlement. Instructor should assign one computation per team. Write equations for settlement of both cohesive and granular soil on flip chart and reference page where C' chart is located. Chose team to present solution. Ask why settlement in the second 10' sublayer is less than top 10' layer settlement.

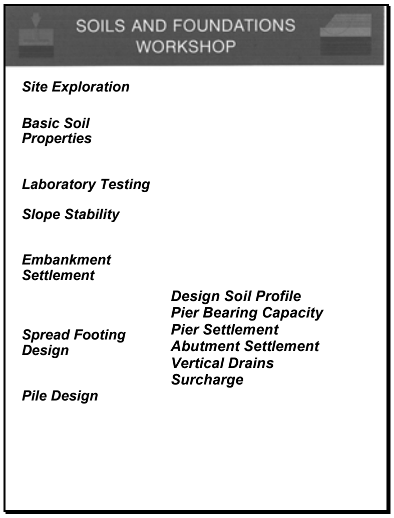
Also ask why settlement in bottom clay layer is greater than upper sand/gravel layer (answer is that clays are one of the problem soils where large settlements may occur under even small loads.

Please refer to the end of the lesson for this exercise.



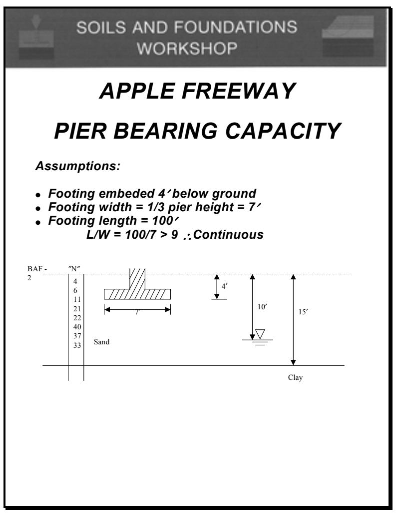
Slide 7-2-20

Please refer to the end of the Participant Workbook for the solution to this exercise.



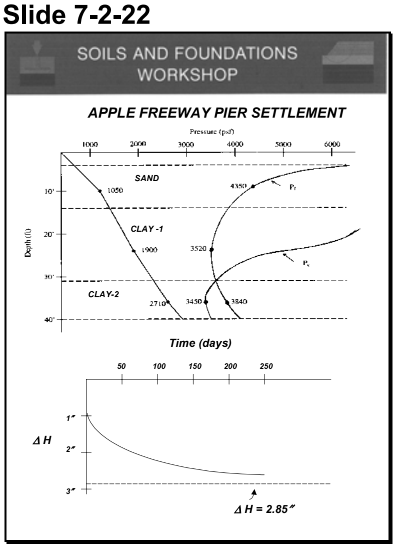
Slide 7-2-21

Show Apple Freeway status of design. Use following visuals to test learning of both bearing capacity and settlement for real project application.



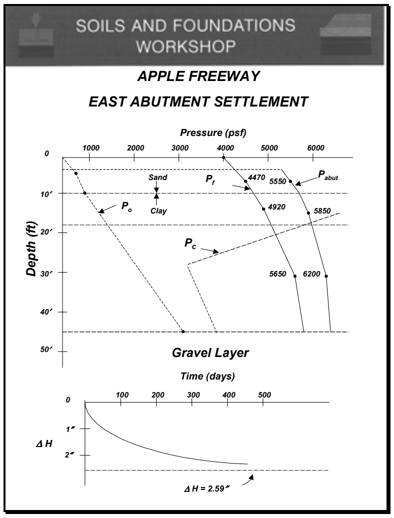
Slide 7-2-22

Ask students what problems they identify with the bearing capacity of the pier footing shown (answer should be water table within the failure zone and the clay layer may influence the bearing capacity).



Slide 7-2-23

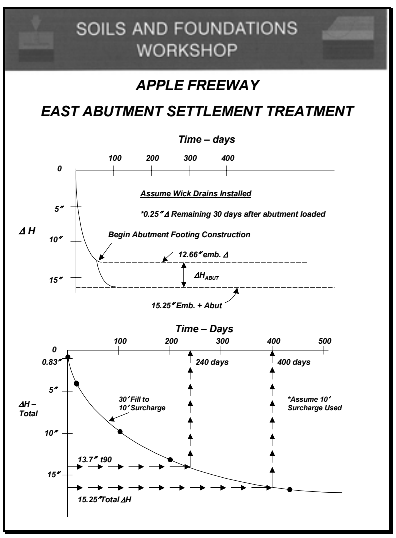
Ask which layers will yield the most settlement at the pier and why (answer is the portion of the clay layer that is not preconsolidated and the top part of the sand layer that is subject to high pressure).



Slide 7-2-24

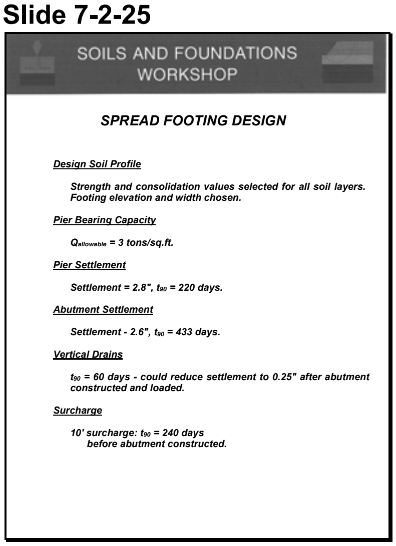
Ask students about the reason for the surprising large amount of settlement on the time settlement plot as the change in pressure is small (answer is that the load above Pc and all in virgin compression).

Also ask if the wick drains decrease settlement magnitude under the structure foundation area (answer is no but time reduced).



Slide 7-2-25

Explain wick drain option (note that if wick drains used for embankment the wicks still function when the footing is placed and that the total settlement occurs quickly but could still cause clearance problems under structure if that was an issue) and surcharge option (note that surcharge for embankment could be left on longer until settlement due to both embankment and footing loads have occurred, then application of footing would result in no settlement).



Slide 7-2-26

After reviewing the design summary, ask if the differential settlement would be small enough to permit the structure to be built "high" (answer is that differential settlement appears to be only 0.2 inches but that is incorrect as the settlements occurs at different rates and an overlay of the time settlement diagrams would show almost 1.5" of temporary differential settlement.
Instructor asks students to open reference manual to the Apple Freeway problem, overviews the solution, and then promotes NHI Shallow Foundations course.

Go to Reference Manual.

Slide 7-2-27

Repeat objectives for lesson 7 topic 2.

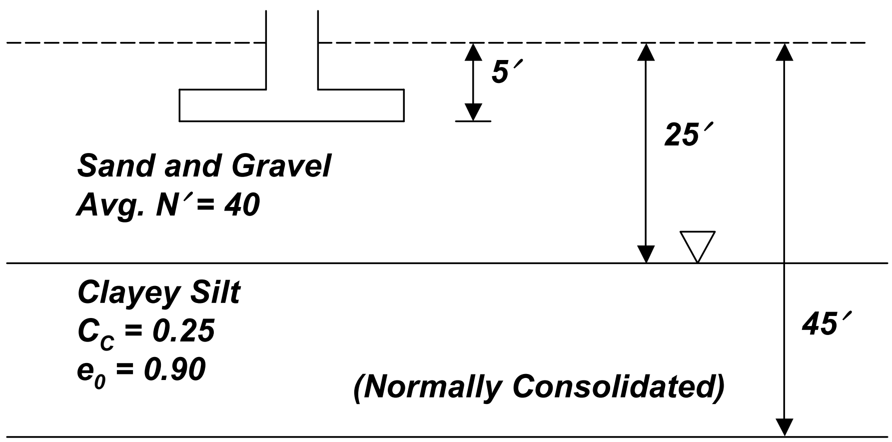
SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 6

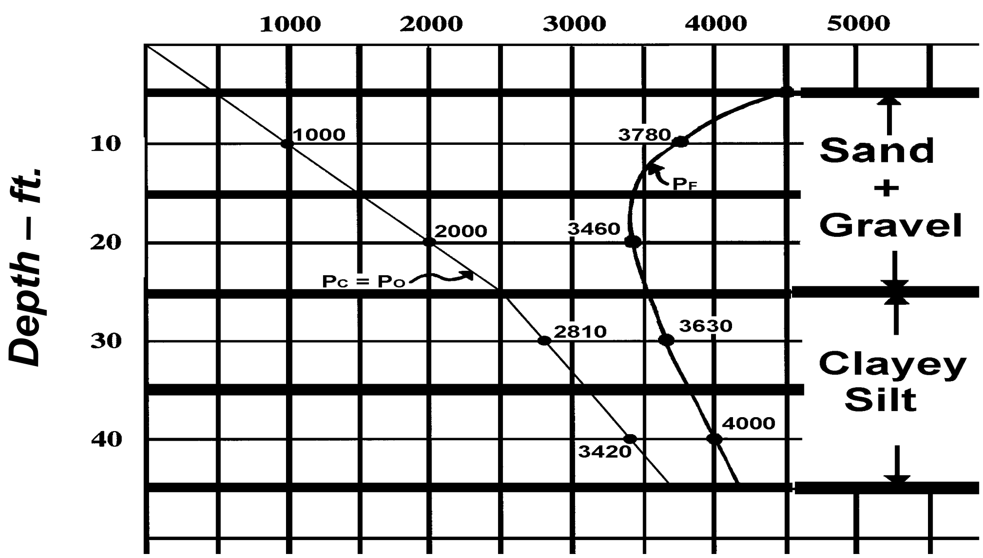
Footing Settlement

Given: Soil Profile and Pressure Diagram Below

Find Footing Settlement Using Increments of 10'



Pressure - psf



SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 6 SOLUTION
Footing Settlement

Sand Layer

$$\Delta H_{\mathbf{sand}} = H \frac{1}{C'} \text{Log} \frac{P_F}{P_o}$$

5' – 15'

$$\Delta H_{\mathbf{s}} = 10 \frac{1}{132} \text{Log} \frac{3780}{1000} (12) = 0.5''$$

15' – 25'

$$\Delta H_{\mathbf{s}} = 10 \frac{1}{132} \text{Log} \frac{3460}{2000} (12) = 0.2''$$

Clay Layer

$$\Delta H_{\mathbf{clay}} = H \frac{C_C}{1 + e_o} \text{Log} \frac{P_F}{P_o}$$

25' – 35'

$$\Delta H_{\mathbf{c}} = 10 \frac{0.25}{1 + 0.90} \text{Log} \frac{3630}{2810} (12) = 1.8''$$

35' – 45'

$$\Delta H_{\mathbf{c}} = 10 \frac{0.25}{1 + 0.90} \text{Log} \frac{4000}{3420} (12) = 1.1''$$

Total Footing Settlement (inches) = 3.6”

LESSON 8

TOPIC 1

Deep Foundation Design – Load Capacity

Structural Foundation Topics

- ***Shallow Foundations (Spread Footings)***
  - *Bearing Capacity*
  - *Settlement*
- ***Deep Foundations***
  - *Load Capacity*
  - *Settlement*
  - *Negative Skin Friction*

Slide 8-1-1

Re-show structural topic slide. Point out that the first step in a deep foundation design is to make sure that you cannot use spread footings, as these are cheaper and more reliable than deep- foundations.

DEEP FOUNDATION DESIGN

Lesson 8 - Topic 1
Load Capacity

Slide 8-1-2

Header

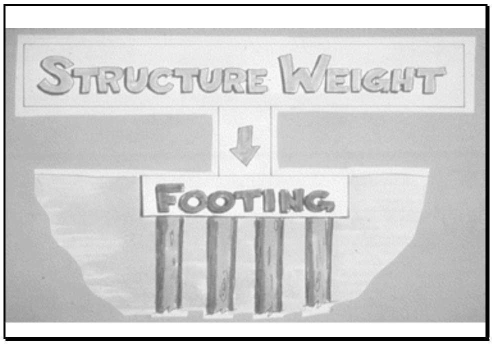
DEEP FOUNDATION DESIGN
Load Capacity

1. Describe Properties of the Pile and the Ground Which Affect Bearing Capacity

ACTIVITY: Static Analysis & Interpretation

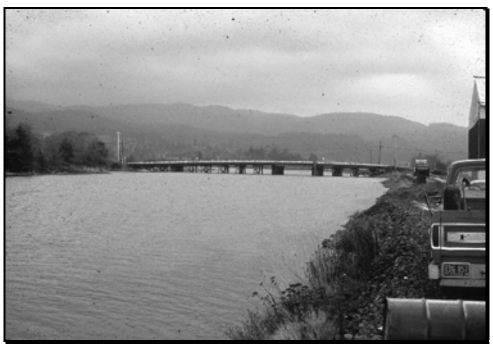
Slide 8-1-3

Objectives



Slide 8-1-4

Schematic of deep foundation. Stress that piles or drilled shafts are structural elements that are used to transfer load through unsuitable to suitable soils. Engineers who specify deep foundations in every situation have forgot this definition in the past. Remind the group of the problems associated with using deep foundations in areas of dense, competent soil conditions (excellent example is case where piles were specified in a surface glacial till deposit that had to pre-augered with a rock auger to achieve the minimum 10' length). However then transition to situation where non-geotechnical factors may require deep foundations; even in competent soils.



Slide 8-1-5

Show a series of situations where non-soil related conditions could make soils at some locations unsuited to carry foundation loads; generally these conditions are related to water or ice. This picture is of a bridge located in a flood plain. Emphasize that the hydraulics engineer should be involved in foundation designs in the vicinity or water crossings.

Slide 8-1-6

This abutment was affected by scour forces that eroded the end fill to a point where the footing was undermined. The point is that embankment material is not sufficient protection against scour forces.

Slide 8-1-7

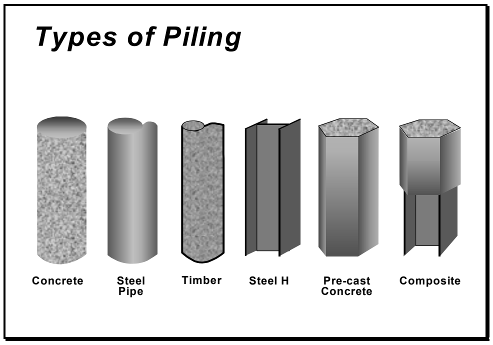
Note that even abutments that are protected by riprap can be subjected to scour forces. The foundation design must account for future removal of soil by water and extended sufficiently below the scour depth to mobilize the required resistance for the foundation loads.

Slide 8-1-8

The presence of ice can cause both lateral and uplift forces on a structure. Deep foundations may be needed to resist those loads.

Slide 8-1-9

This case history demonstrates how pier footings, even those on piles, can fail if scour is not accounted for. This bridge was founded on short timber piles. A 50-year storm caused scour around the pier to about half the length of the piles. The remaining pile embedment was inadequate to resist the applied structure and water forces. The downstream piles plunged and the pier rotated, broke the upstream piles and fell in to the scour hole. The point to make is that rational design needs to accounts for all factors that influence the foundation.



Slide 8-1-10

At this point inform students that only pile foundations will be dealt with in this course. Other deep foundations types such as micropiles or drilled shafts will not be covered. However the basic concepts discussed here are applicable to all deep foundation types. Show pile types; stress differences in materials, shapes and available dimensions make selection of optimum difficult. Ask students how they select the pile type for their projects.

Individual Piles

Method of Estimating Load Capacity

- ***Load Test***
- ***Dynamic Formula***
- ***Static Analysis***

Slide 8-1-11

Methods of load capacity determination

Slide 8-1-12

Note load testing requires extensive field mobilization and is not commonly done prior to design except on major projects. Even in those cases, useful soil design values are not obtained unless the test elements are instrumented for load transfer.

Slide 8-1-13

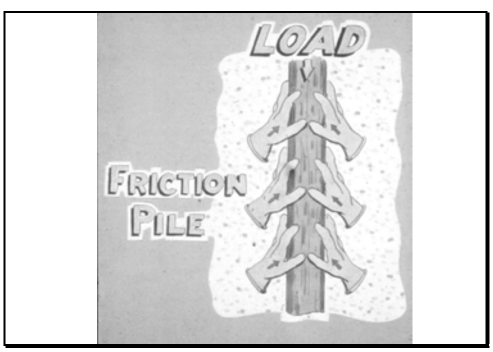
Same for driving test piles prior to design. As in the case of load tests, the mobilization of equipment to install foundation elements is not commonly done in design.

Steps in Rational Pile Selection

- ***Adequate Subsurface Investigation***
- ***Soil Profile Development***
- ***Appropriate Lab/Field Testing***
- ***Selection of Soil Design Parameters***
- ***Static Analysis***
- ***Applied Experience***

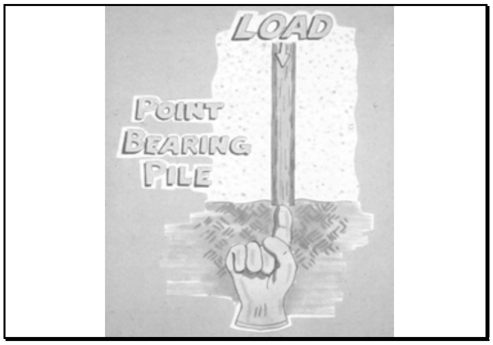
Slide 8-1-14

Bottom line is that the designer usually relies on the soil data to predict the load capacity of deep foundations during the design phase. Advise the students that the computational process is much more difficult than for spread footings and several factors influence capacity. Ask students what factors they think influence pile capacity.



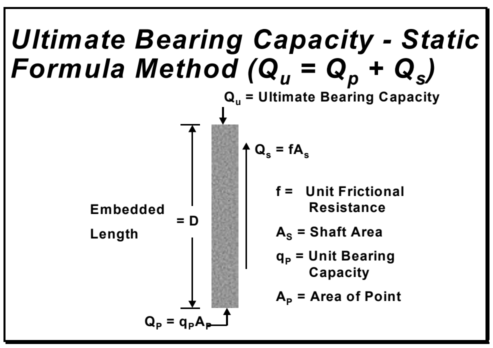
Slide 8-1-15

Next 2 slides describe mechanism of load transfer. Relate skin friction to a person trying to hold a rod when someone is pushing on the rod. If the rod is smooth, the rod slips through your hands more easily then if the rod is rough. The same concept will apply to mobilization of skin resistance by deep foundation elements.



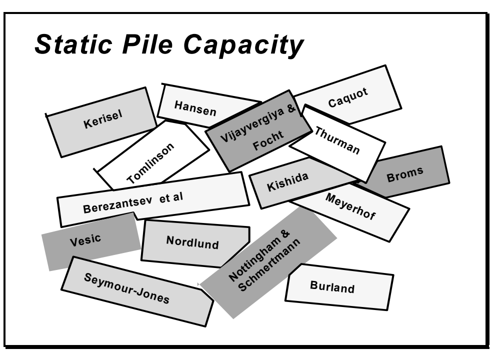
Slide 8-1-16

Describe mechanism of load transfer for end bearing. Relate the tip resistance developed to the resistance developed by a spread footing.



Slide 8-1-17

Overview the concept of static analysis for pile capacity prediction.



Slide 8-1-18

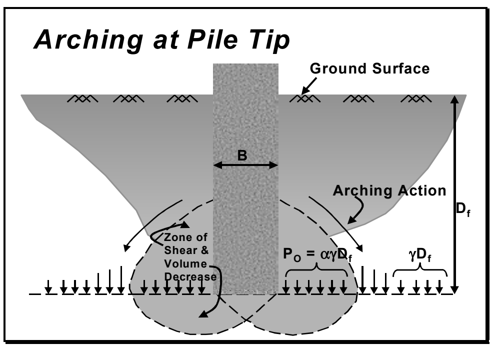
Note that many efforts have been made to refine predictive accuracy but no one method is completely accurate. Also all methods do not apply to all soil types; so we will recommend a different method for cohesive and granular soils.

ALLOWABLE LOAD ON PILES IN COHESIONLESS SOILS

- ***General failure mechanism understood***
- ***Some uncertainty in effects of pile installation on load transfer in both skin friction and end bearing***

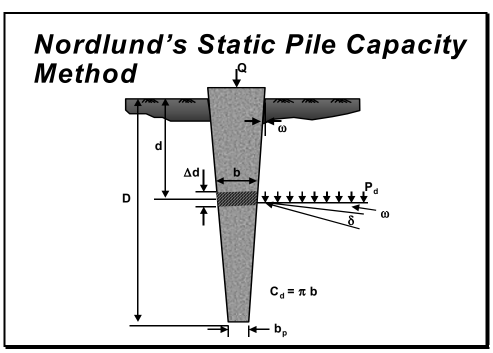
Slide 8-1-19

Introduce cohesionless soil bearing capacity for pile foundations. Mention that FHWA has developed a database of load test information to assist in quantifying load transfer variables and to permit assessment of different methods of static analysis.



Slide 8-1-20

Explain how simple spread footing concepts apply until the pile tip reaches a distance below ground where ground uplift can no longer occur (about 20 to 40 diameters). Explain how capacity is affected by both the densification around the shaft and the pressure reduction at the tip due to arching. Admit that this concept is difficult for non-geotechnical engineers to grasp. The following slides will overview the method of computation of capacity of piles in granular soils. Students should be told to watch the lecture and then the instructor will cover the material again in the reference manual.



Slide 8-1-21

Overview Nordlund's equation, which is, based on load test results.

Ultimate Capacity of Non-Tapered Piles in Granular Soils

$Q_u = Q_S + Q_P$

$Q_u = K_\delta \, C_F \, P_d \sin\delta \; C_d \, D + A_P \, \alpha \, P_D \, N'_q$

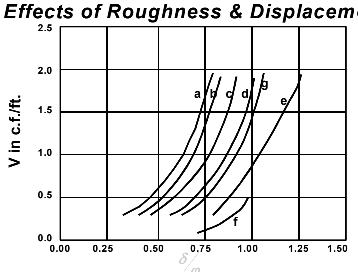
Unknowns are K_δ, C_F, δ, α, N'_q

Slide 8-1-22

First explain that the equation shown above is divided into skin friction and end bearing. The terms in each section are composed of soil and pile properties. Each property affects the capacity. The first step in the application of the equation is to assume a particular pile type and a particular soil profile. Then half of the terms are known in the equation. The following slides contain a breakdown the components of the computation of skin friction. Then we deal with end bearing.

Skin Friction in Granular Soils

- Effects of Roughness & Displacement

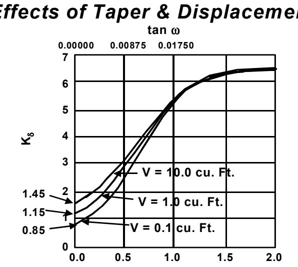


Slide 8-1-23

Explain that the skin resistance is dependent on the load transfer between the pile and the soil. Both the roughness of the pile and the soil displaced by the pile affect the angle of friction developed between the pile and the soil. The volume of soil displaced by the pile has a profound effect on skin friction. This chart is entered with the volume of the soil displaced per foot. The chart has been developed for piles of different roughness and shape. If the volume displaced per foot and the pile type are known, the ratio between the friction angle and the angle of friction between the soil and the pile can be found.

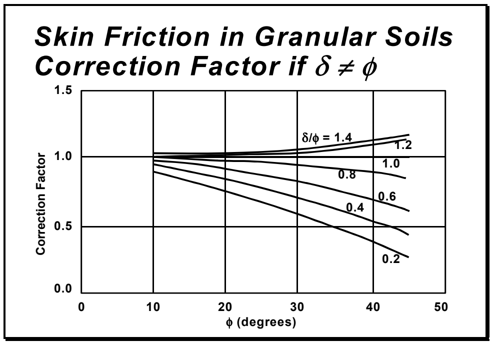
Skin Friction in Granular Soils

- Effects of Taper & Displacement



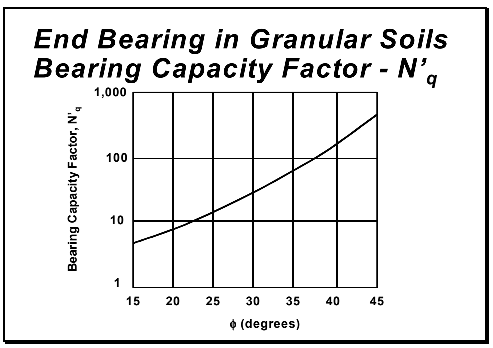
Slide 8-1-24

Taper and soil displacement also affect the lateral pressure against the side of the pile; much as the lateral pressure against a retaining wall is affected by the angle of the backwall and the compaction of the soil. The lateral pressure is needed to find the normal force against the side of the pile.



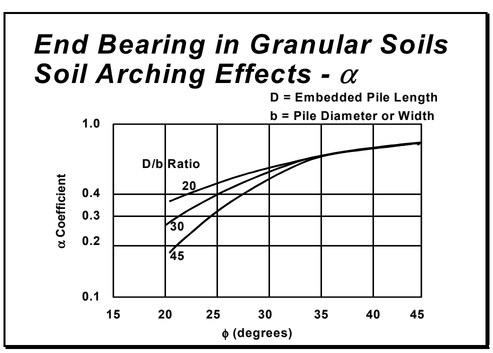
Slide 8-1-25

Finally a correction factor is applied to situations where the angle of friction does not equal the friction angle between the pile and the soil. This correction is needed to account for the theoretical simplification of equality of both angles that was used to develop the initial equation. At this point all the unknowns have been found to find the skin friction.



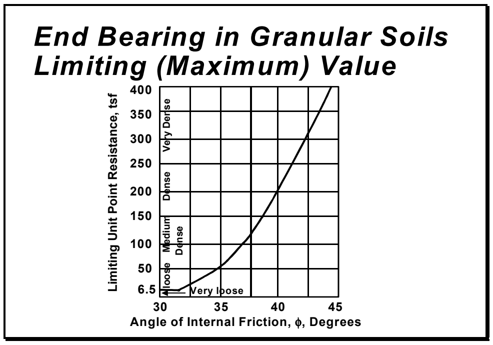
Slide 8-1-26

The end bearing computation contains two unknowns. The first is the bearing capacity factor. However we explained the concept of bearing capacity in the previous lesson. Then ask who can tell me the bearing capacity factors that were used for spread footing bearing capacity (answer is N_c, N_γ, N_q. Then ask why is only N_q used to pile design… answer is that embedments is the overriding factor for deep foundation… ask students to remember the effect of embedding the footing in the granular soil example of the previous lesson).



Slide 8-1-27

The end bearing will also be affected by the amount of arching that occurs when soil displacement occurs. The arching is depending on the angle of friction of the soil and the number of diameters that the tip is located below ground.



Slide 8-1-28

Finally introduce the concept of limiting end bearing. Explain that the results of load tests confirmed that the original Nordlund equation over predicted end-bearing resistance. This separate computation is done and compared to the original end bearing resistance. The smaller of the two values is chosen to prevent over prediction of the end bearing.

Slide 8-1-29

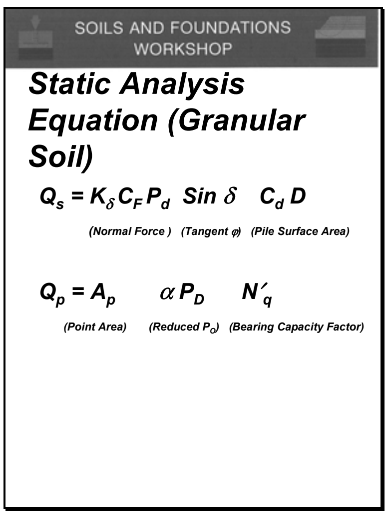
Ask, which end treatment procedures the highest end bearing; first is this flat plate treatment.

Slide 8-1-30

Second is this conical point treatment.

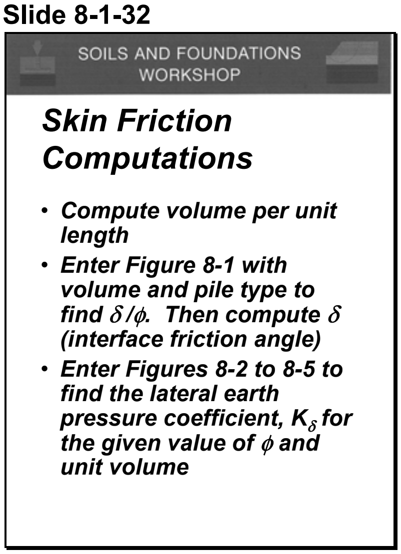
Slide 8-1-31

Third is this open-end pipe pile. Before giving the answer, go to the flip chart and draw the flat plate and show the failure occurs by the formation of a shear wedge in the soil below the plate (soil to soil shear). Then draw the conical point and show where the failure occurs, (along the point face in a steel to soil shear). The answer is the flat plate or a plugged open-end pile as these are soil-to-soil shear.



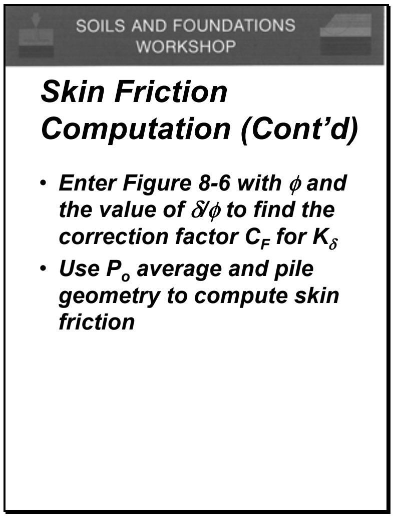
Slide 8-1-32

Ask students to open reference manual to the deep foundation section. Overview the information in the manual up to the static analysis section. Then ask students to follow along in their reference manual as the computation process is explained. Mention that an example will follow the lecture and a student exercise will be done after cohesive soils are explained in the next session. Encourage students to ask questions about the process. Then the instructor begins the discussion by relating the equations for skin friction and end bearing to practical aspects.



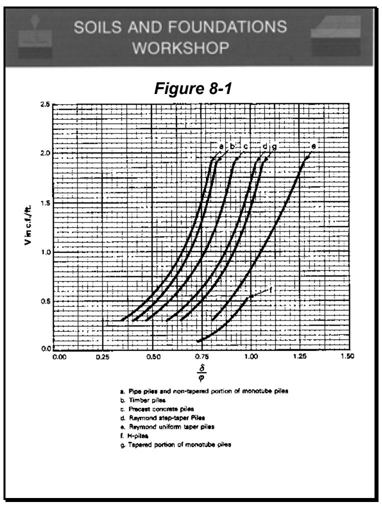
Slide 8-1-33

Instructor walks students through computational process for granular soils in the next two overheads. Note that this process may be difficult for non-geotechnical engineers to understand. The concepts must be clearly and slowly stated. Read each bullet. If a figure is referred to on the bullet, go to that figure and explain where to enter the figure and what value is to be determined.



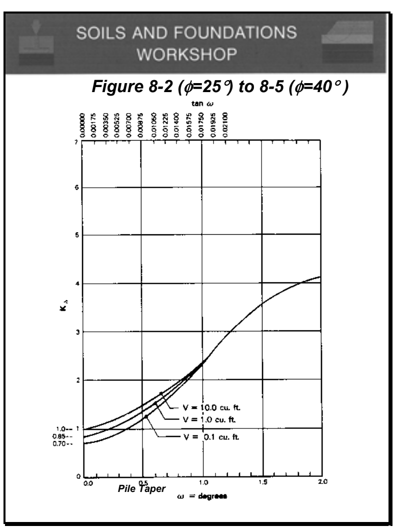
Slide 8-1-34

Instructor walks students through computational process for granular soils. Note that this process will be difficult for non-geotechnical engineers to understand. The concepts must be clearly and slowly stated.



Slide 8-1-35

Instructor walks students through computational process for granular soils. Note that this process will be difficult for non-geotechnical engineers to understand. The concepts must be clearly and slowly stated.

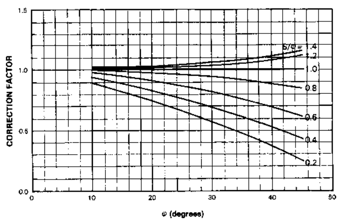


Slide 8-1-36

Instructor walks students through computational process for granular soils. Note that this process will be difficult for non-geotechnical engineers to understand. The concepts must be clearly and slowly stated. In this chart, note that different figures are used for different F̥ values.

SOILS AND FOUNDATIONS WORKSHOP

Figure 8-6



Slide 8-1-37

Instructor walks students through computational process for granular soils. Note that this process will be difficult for non-geotechnical engineers to understand. The concepts must be clearly and slowly stated.

SOILS AND FOUNDATIONS WORKSHOP

End Bearing Rules Granular Soils

- ***P_D should not exceed 3000 psf for end bearing computations***
- ***Q_p must be compared to the limiting maximum end bearing for the soil friction angle selected.***

Slide 8-1-38

Instructor walks students through computational process for granular soils. Note that this process will be difficult for non-geotechnical engineers to understand. The concepts must be clearly and slowly stated.

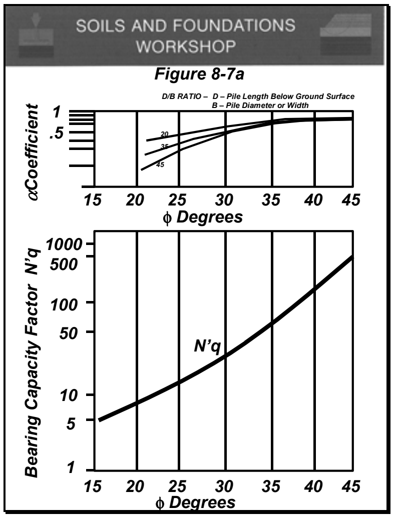
SOILS AND FOUNDATIONS WORKSHOP

End Bearing Rules Granular Soils (Cont'd)

- ***Q_{LIM} = (Unit Point Resistance from figure 8-7B)(Pile End Area)***
- ***The lesser of Q_{LIM} or Q_p is used as the end bearing value***

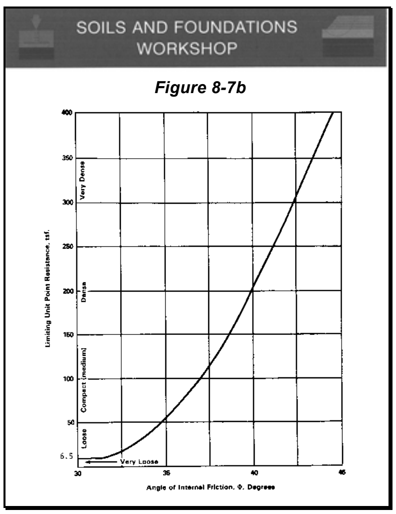
Slide 8-1-39

Instructor walks students through computational process for granular soils. Note that this process will be difficult for non-geotechnical engineers to understand. The concepts must be clearly and slowly stated.



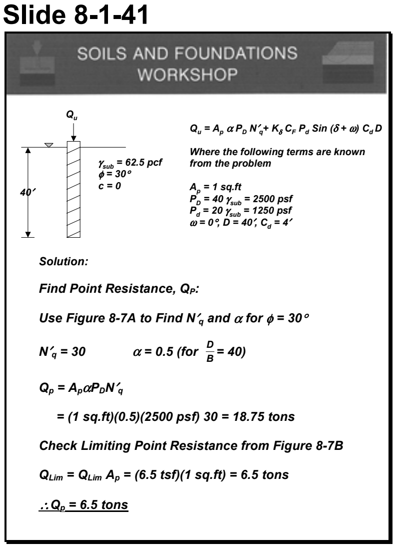
Slide 8-1-40

Instructor walks students through computational process for granular soils. Note that this process will be difficult for non-geotechnical engineers to understand. The concepts must be clearly and slowly stated.



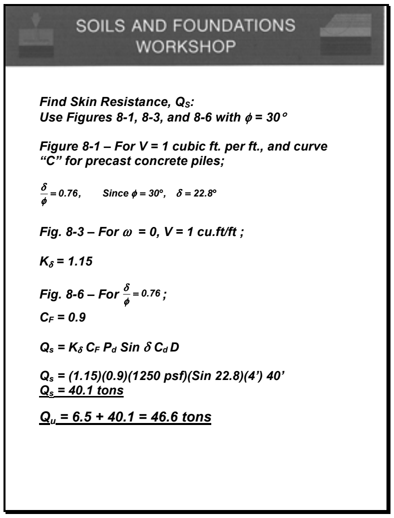
Slide 8-1-41

Note to the group that this figure is in tons per square foot.



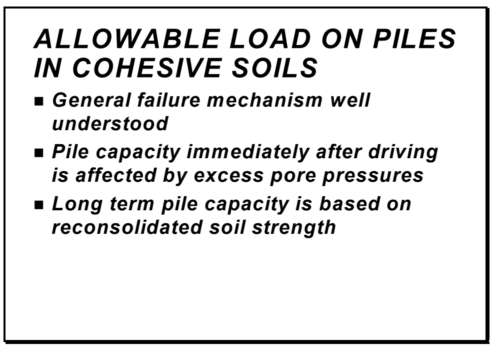
Slide 8-1-42

Instructor uses all previous information in example solution for a pile in a granular soil. The example will initially pull together all the concepts into a defined computation. The instructor should show where all values are obtain by asking students to go to appropriate charts and directing them to enter with the known value to find the desired value.



Slide 8-1-43

After completing the solution, ask if the value computed was in the ballpark of what the students expected. Usually the students think the value is too low but point out the water table is at the ground surface and has a large effect on the results. Mention that the group will get a chance to do a student exercise after the next session on cohesive soils is explained.



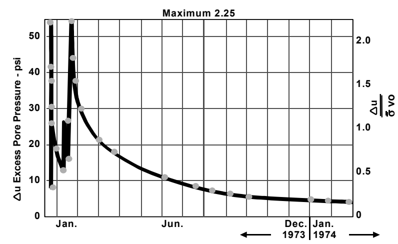
Slide 8-1-44

Introduce cohesive soil capacity determination.

Slide 8-1-45

Case history to demonstrate affects of pore pressure increase on pile capacity with time in clay. These closely spaced, closed end pipe piles were driven into a soft clay layer that was over 200' thick. The piles were designed to mobilize all resistance in skin friction at an estimated length of about 140'. When each pile was driven, a conical pile of liquefied clay was squeezed out of the ground and formed around the pile. While driving the third pile, the first pile heaved a short distance out of the ground. Efforts to redrive that pile resulted in heave of adjacent piles. This was due to the lack of skin friction to hold the piles in place as high pore pressures caused both reduced friction and increased pressures under closed end plates. The solution to prevent the heave was to wait until set-up occurred before installing adjacent piles. In this case the contractor drove every other pile with out any heaving and then returned to drive out the remainder after skin friction was mobilized.

Pore Pressure – South Bay Bridge
Pier No. 3, Piezometer Nos. 1 & 2



Slide 8-1-46

Case history to demonstrate the magnitude and time for dissipation of pore pressures. Piezometers were installed about three diameters away from friction piles driven into a 400' thick clay deposit to measure the excess pore pressure. The readings were used to determine the length of the waiting period prior to beginning a load test. Note the initial pressures exceeded 50 psi and took about 10 days to return to normal when the test pile was driven. Also note the time after driving the group of 60 piles for the pressure to return to normal was very large, i.e., months

Ultimate Capacity of Piles in Cohesive Soils

$$Q_{ult} = C_a C_d D + 9 C_u A_P$$

Slide 8-1-47

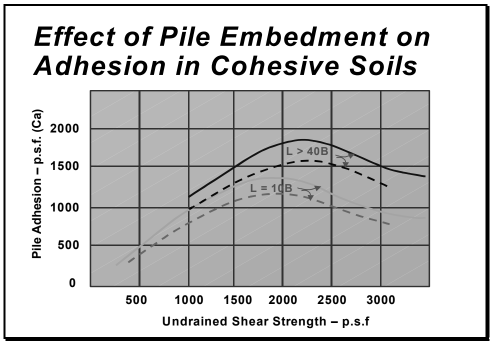
Introduce basic concept of capacity in clays and explain factor influencing capacity.

Adhesion on Piles in Saturated Clay (Circa 1960)

Material	*Cohesion (psf)*	*Adhesion (psf)*
Concrete and Timber	*Soft 0 – 750* *Firm 750 – 1500* *Stiff 1500 - 3000*	*Soft 0 – 750* *Firm 750 – 1250* *Stiff 1250 – 1400*
Steel	*Soft 0 – 750* *Firm 750 – 1500* *Stiff 1500 – 3000*	*Soft 0 – 600* *Firm 600 – 1050* *Stiff 1050 – 1200*

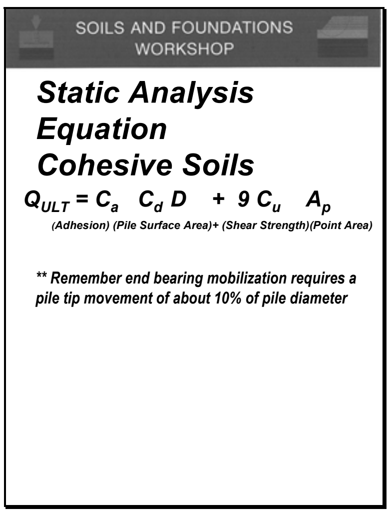
Slide 8-1-48

In the early 1960's tables were developed to find adhesion between clay soils and piles. Begin by explaining the impact of roughness on the pile capacity. Rough piles mobilize more skin friction than smooth piles. Then explain why soft clays will reconsolidate back to their original strength while overconsolidated clays will suffer a permanent reduction in strength. Note that this table is based only on early historical data for relatively short piles and has since been improved.



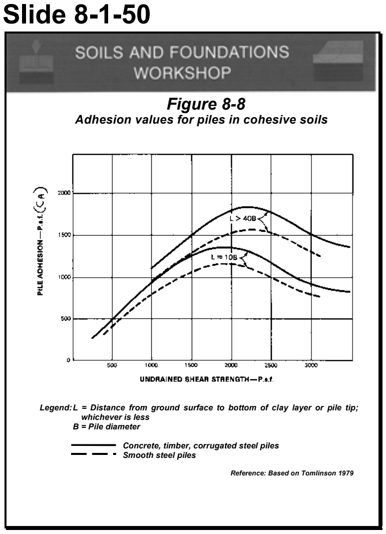
Slide 8-1-49

First note that this graph contains the relations between roughness and soil strength that were just explained. These facts have been well known for many years. However a third factor has been found to also be important; the severe disturbance to the clay that occurs near the ground surface due to unsupported pile vibrations during driving. Research has indicated that the reductions in strength are the greatest generally within about 10 diameters of the ground surface and no strength reduction is considered below a depth of 40 diameters.



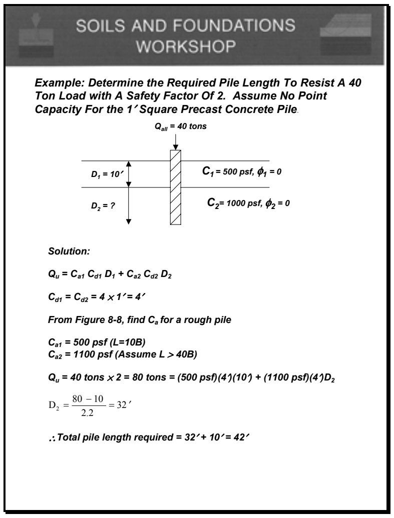
Slide 8-1-50

Relate the factors in the equation to practical terms.



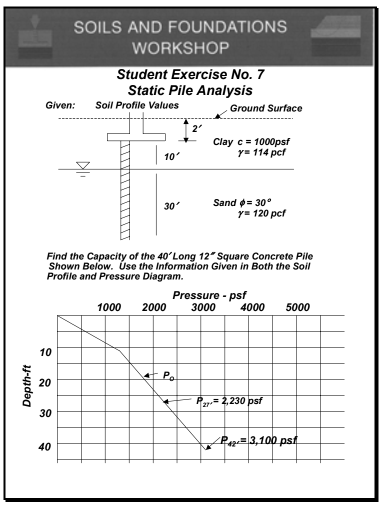
Slide 8-1-51

Demonstrate how to obtain adhesion values for deign.



Slide 8-1-52

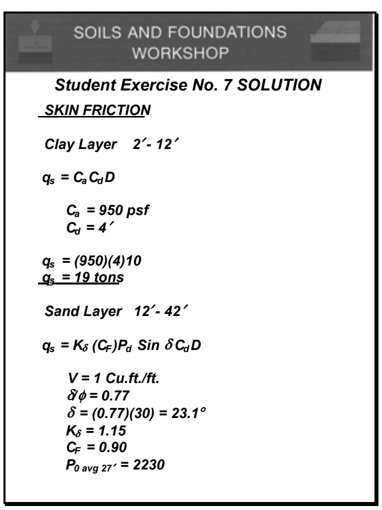
Instructor completes an example computation to summarize the cohesive capacity computational process. This process is similar to the previous granular example but simpler to comprehend. After the example recall the granular example computation process and compare to the cohesive method. Then ask how reliable the answer is? (answer is to ask students how reliably the undrained shear strength was determined…the equation theory is correct but the answer depends on the soil properties to be accurately determined.



Slide 8-1-53

Instructor asks students to do the student exercise. If time is an issue, the instructor can assign different part of the computation to different teams. Student exercise involves computation of static capacity for a pile in both cohesive and cohesionless soils. The purpose of the exercise is to test comprehension of the computational process and to evaluate the students learning of the definition of a pile. Instructor asks team to present solution.

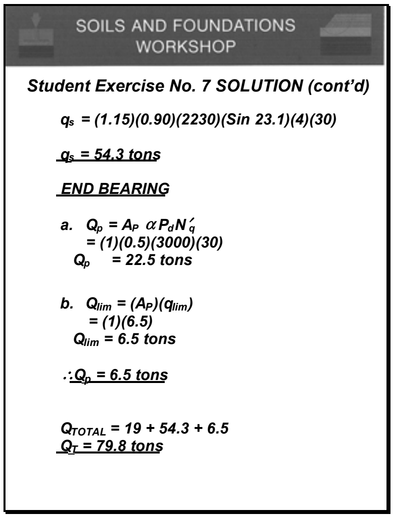
Please refer to the end of the lesson for this exercise.



Slide 8-1-54

Page one of solution to problem.

Please refer to the end of the Participant Workbook for the solution to this exercise.

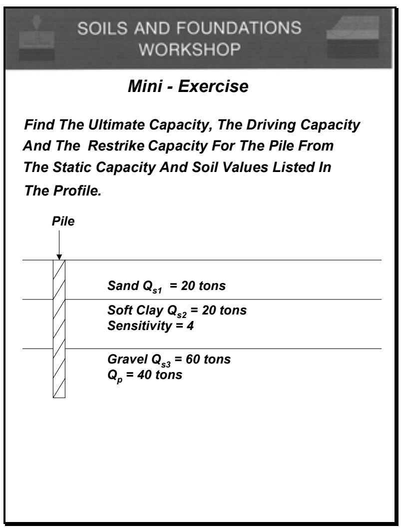


Slide 8-1-55

Page 2 of the solution. After the students have completed the explanation of the computation, ask what ultimate value would be used for the pile design? The answer is the skin friction in the sand and the end bearing or about 61 tons as the clay will consolidate if load is transferred to the deposit. Students should determine that if the clay was suitable for foundation support then a spread footing would have been the best solution. Go to the reference manual and point out the section on practical aspects of pile design.

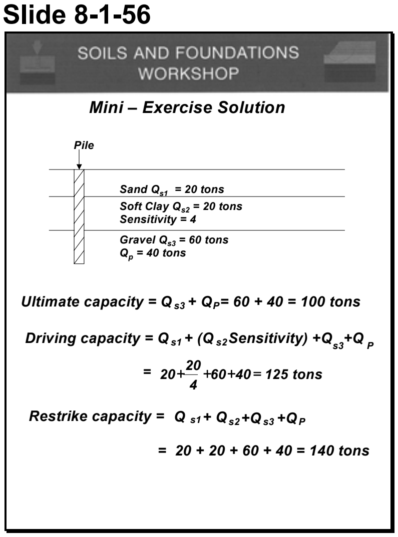
At this point the instructor demonstrates both SPILE and Driven software programs and emphasizes the ability of the programs to compare various pile alternates.

Please refer to the end of the Participant Workbook for the solution to this exercise.



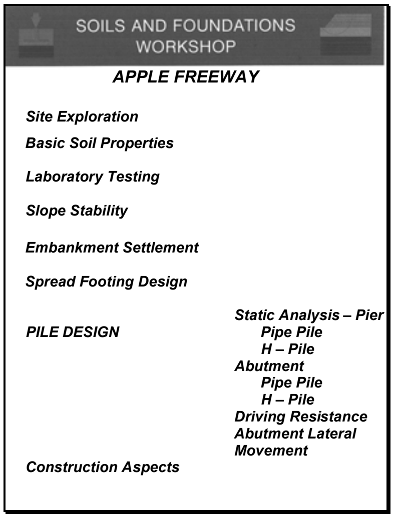
Slide 8-1-56

After introducing the terms; ultimate capacity, initial driving capacity and end of driving capacity in the DRIVEN demo, ask student to compute each in this simple exercise. Do not assign to teams but do as group exercise. Put on flip chart.



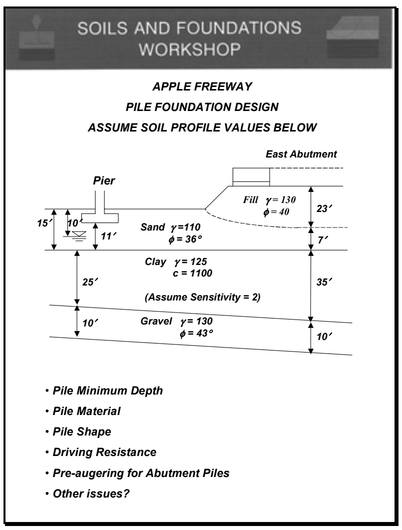
Slide 8-1-57

Please refer to Reference Manual 8-19 for solution, which follows.



Slide 8-1-58

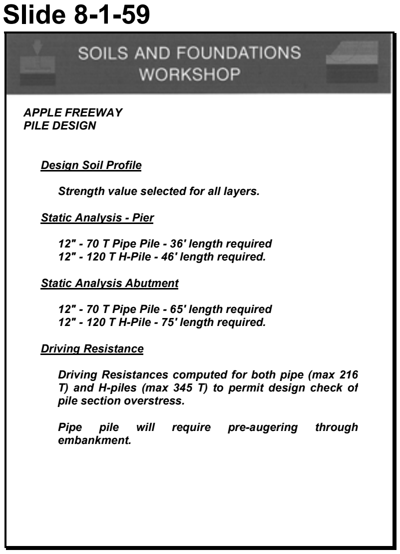
Summarize status of Apple Freeway design.



Slide 8-1-59

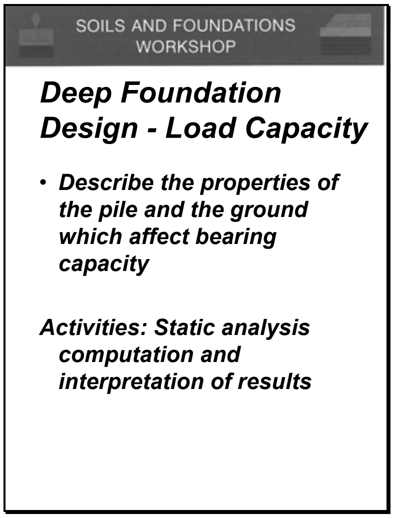
Ask students their opinions on the bullet topics.

Then ask about other issues, which need to be considered in project design that influence the performance of any foundation.



Slide 8-1-60

Summarize design results for Apple Freeway pile design



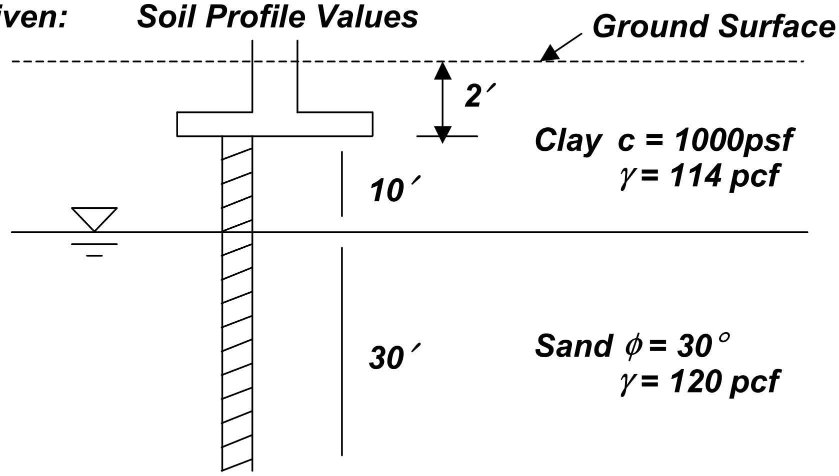
Slide 8-1-61

Repeat objectives for lesson 8 topic 1.

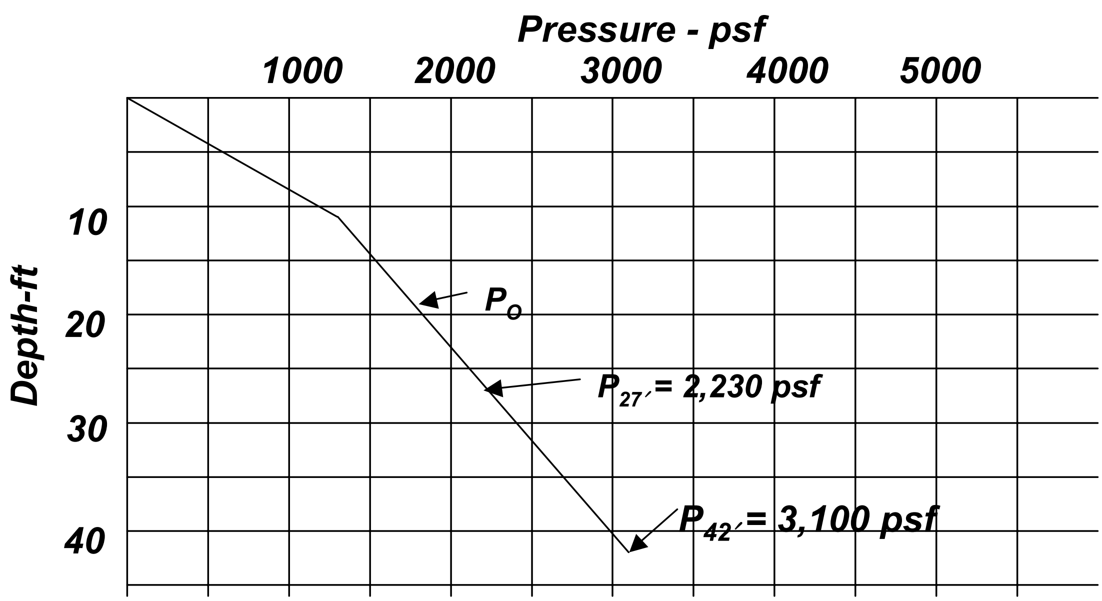
SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 7
Static Pile Analysis

Given: ***Soil Profile Values***



Find the Capacity of the 40´ Long 12″ Square Concrete Pile Shown Below. Use the Information Given in Both the Soil Profile and Pressure Diagram.



SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 7 SOLUTION

SKIN FRICTION

Clay Layer 2′- 12′

$q_s = C_a C_d D$

$C_a = 950$ psf

$C_d = 4'$

$q_s = (950)(4)10$

$q_s = 19$ tons

Sand Layer 12′- 42′

$q_s = K_\delta (C_F) P_d \sin \delta \, C_d D$

V = 1 Cu.ft./ft.

$\delta/\phi = 0.77$

$\delta = (0.77)(30) = 23.1^\circ$

$K_\delta = 1.15$

$C_F = 0.90$

$P_{0\ avg\ 27'} = 2230$

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 7 SOLUTION (cont'd)

q_s = (1.15)(0.90)(2230)(Sin 23.1)(4)(30)

q_s = 54.3 tons

END BEARING

a. $Q_p = A_P \alpha P_d N'_q$
= (1)(0.5)(3000)(30)
Q_p = 22.5 tons

b. $Q_{lim} = (A_P)(q_{lim})$
= (1)(6.5)
Q_{lim} = 6.5 tons

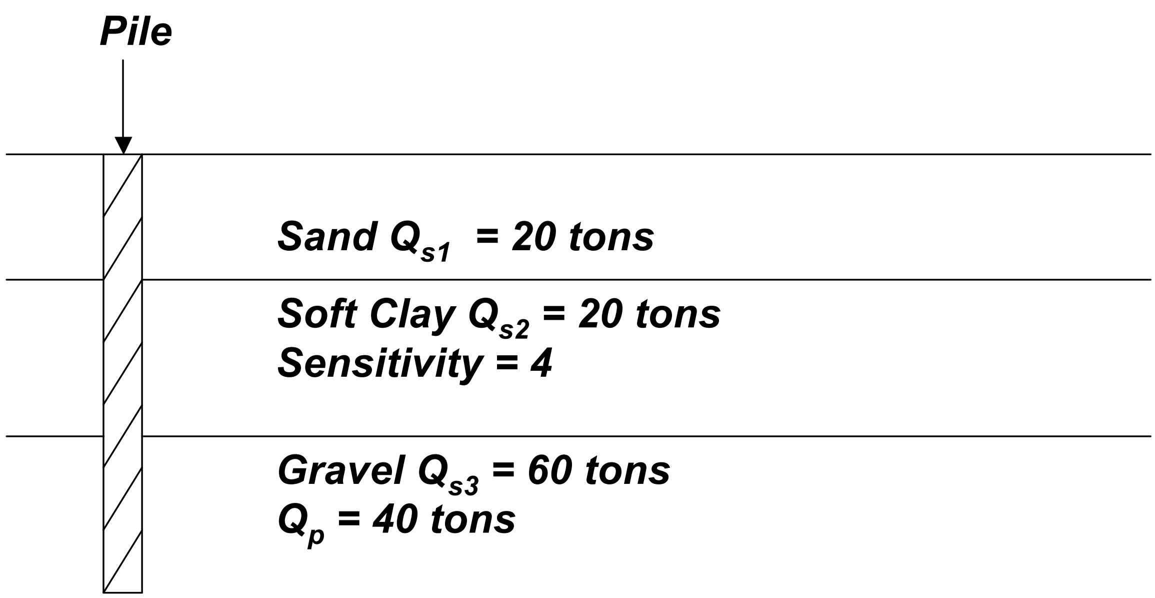
$\therefore Q_p$ = 6.5 tons

Q_{TOTAL} = 19 + 54.3 + 6.5
Q_T = 79.8 tons

SOILS AND FOUNDATIONS WORKSHOP

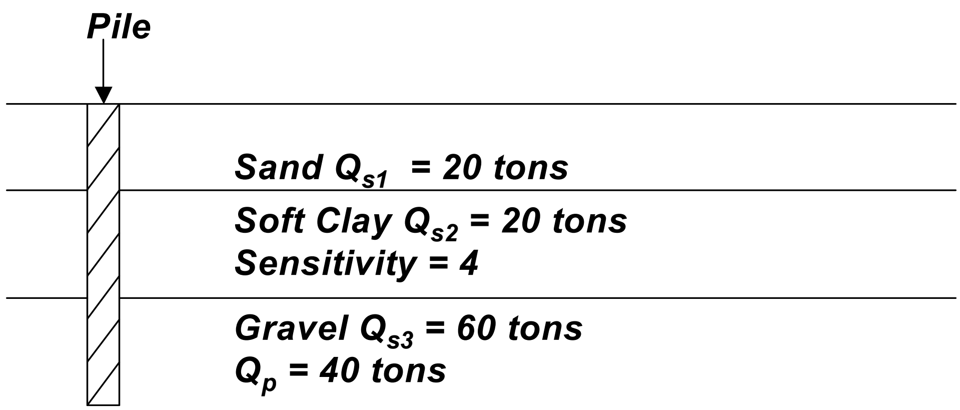
Mini - Exercise

Find The Ultimate Capacity, The Driving Capacity And The Restrike Capacity For The Pile From The Static Capacity And Soil Values Listed In The Profile.



SOILS AND FOUNDATIONS WORKSHOP

Mini – Exercise Solution



Ultimate capacity $= Q_{s3} + Q_P = 60 + 40 = 100$ ***tons***

Driving capacity $= Q_{s1} + (Q_{s2} Sensitivity) + Q_{s3} + Q_P$

$$= 20 + \frac{20}{4} + 60 + 40 = 125 \text{ tons}$$

Restrike capacity $= Q_{s1} + Q_{s2} + Q_{s3} + Q_P$

$$= 20 + 20 + 60 + 40 = 140 \text{ tons}$$

LESSON 8

TOPIC 2

Deep Foundation Design – Pile Groups

DEEP FOUNDATION DESIGN

Lesson 8 - Topic 2
Pile Groups

Slide 8-2-1

Header

DEEP FOUNDATION DESIGN
Pile Groups

1. Recognize the Effects of Pile Spacing, Settlement and Negative Skin Friction

ACTIVITY: Question-Answer

Slide 8-2-2

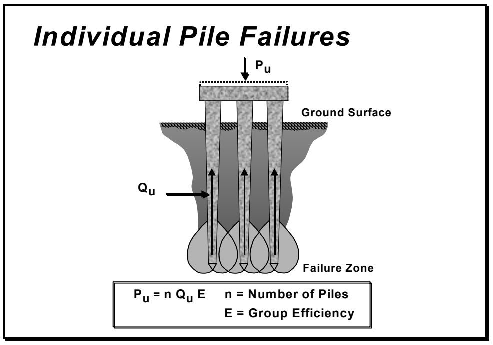
Objectives

Pile Group Failure Modes

- *Individual Pile Failure*
- *Block Failure*

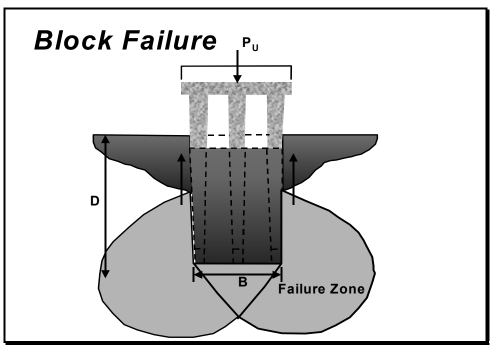
Slide 8-2-3

Introduce pile group behavior.



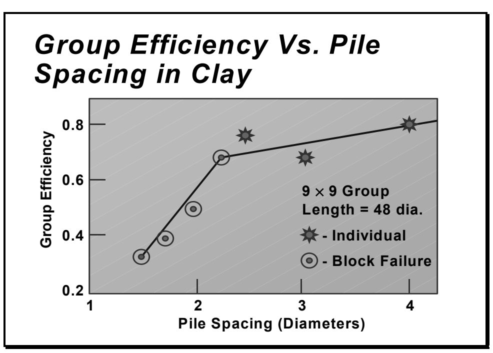
Slide 8-2-4

Explain the importance of pile spacing on the mode of pile failure. Begin with the case of individual pile failure as this is the only case considered for granular soils and the only practical case for cohesive soils. Note that the example we will use shows the pile cap out of the ground as the contribution of the pile cap to total pile group capacity is beyond the scope of this course. Then describe that the group fails by first mobilizing skin friction, then mobilizing the remainder of the end bearing until failure occurs. The skin and end bearing are both affected by the spacing of the piles in the group. In general as the spacing becomes closer, the capacity decreases. The relationship of the spacing and capacity is called the efficiency of the group and is denoted by the term, E. The group ultimate capacity is computed as the efficiency times the number of piles times the ultimate capacity of a single pile.



Slide 8-2-5

Continue the explanation of the importance of pile spacing on the mode of pile failure. Note that in cohesive soils when the piles are spaced too close (less than about 2.5 diameters center to center), the interior piles in the group cannot fully mobilize their capacity and capacity depends on the soil resistance around the periphery of the group. In this case the soil contained in between the piles will move down in a block fashion with the group. Such close spacing in cohesive soils should be avoided as block failure results in very low group capacity and pile efficiency. Block failures are uncommon as codes such as AASHTO restrict the center to center pile spacing to 3 diameters.



Slide 8-2-6

Reinforce the recommendation that close pile spacing in clay is to be avoided by showing this research on the reduction in efficiency.

Pile Group Capacity in Sand

- ***For general sand case use E = 100%***

$$P_{ult} = n\ Q_{ult}$$

Slide 8-2-7

Show equations for pile group capacity in sand. Note that research has shown that the efficiency can exceed 1.0 for closely spaced groups in sand due to densification. However efficiency values for design are suggested to be limited to 1.0.

Pile Group Capacity in Clay

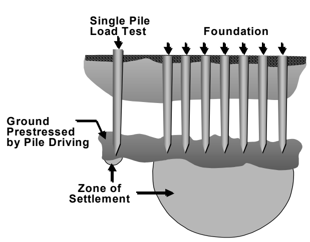
- ***For center to center pile spacing of 3D***
  - *E = 70%*
- ***For center to center pile spacing of 6D***
  - *E = 100%*

$$P_{ult} = n\ E\ Q_{ult}$$

Slide 8-2-8

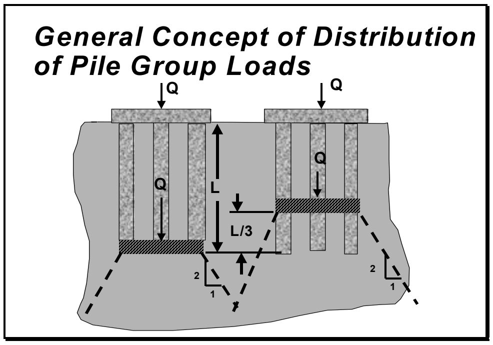
Show recommended equations for pile group capacity in clay and refer the students to standard specifications such as AASHTO for more information.

Settlement of Pile Groups in Sand (After Skempton)



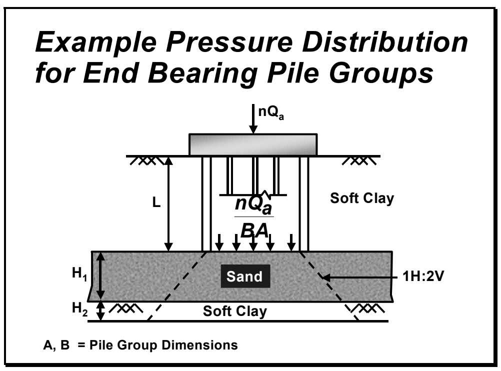
Slide 8-2-9

Introduce the concept of pile group settlement. Begin by noting that pile groups in granular soils cause little or no settlement unless the deposit is underlain by compressible soils. In that case the dimensions of the pile group become very important as the depth to which pressure is distributed is related to the group dimensions. Also note that the settlement results of a load test on a single pile which is tipped just above a soft deposit, may not be representative of the group settlement. This reinforces the need for an adequate subsurface investigation.



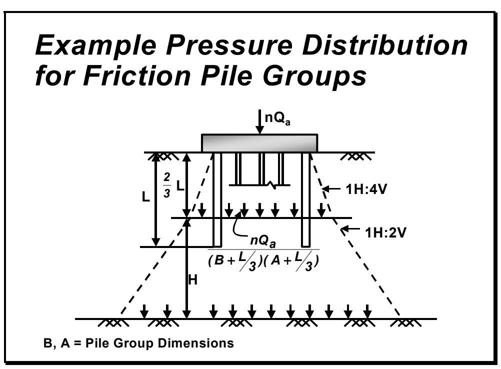
Slide 8-2-10

Show the computational process for pile settlement. Note that the general process is to assume that the group load is transferred to a fictitious footing located at either the pile tips for a predominately end bearing design or at the third point up from the tips for a predominately friction design.



Slide 8-2-11

Expand on the computational process for settlement of end bearing pile groups.



Slide 8-2-12

Expand on the computational process for settlement of friction pile groups. Note the need to find the appropriate dimensions of the fictitious footing by the procedure shown.

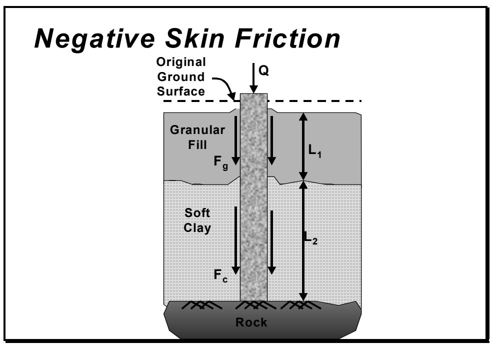
Settlement Magnitude

$$\Delta H = H \frac{C_c}{1+e_o} Log \frac{P_o + \Delta P}{P_o}$$

Where: ΔH = Settlement
H = Layer thickness
C_c = Compression Index
e_o = Initial voids ratio
P_O = Overburden Pressure
ΔP = Change in Pressure

Slide 8-2-13

Show the basic equation for computation of pile settlement. Mention that pile group settlement is usually smaller than the settlement for a typical footing located at ground surface. Ask the students to comment on which terms in the equation would cause a reduced settlement for the pile design (answer is H because the foundation usually reduces the thickness of compressible soils below the group; but more particularly the ratio of the log of the pressures. Note the value of Po is small at the ground surface and the ratio is large; but at depth the value of Po is large and the ratio small).



Slide 8-2-14

Introduce the concept of negative skin friction. Emphasize that the worst problems can occur at abutment locations where the piles are driven before the embankment settlement is complete.

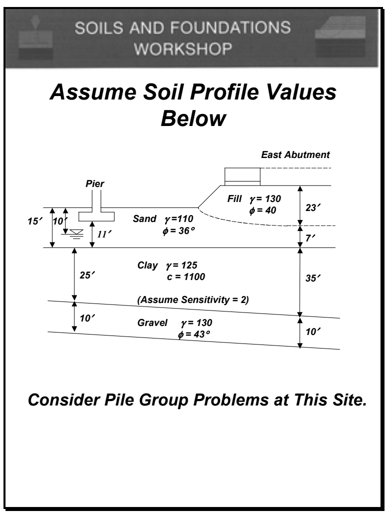
Slide 8-2-15

Show bitumen coating treatment and emphasize that this is only applied in the subsoil zone where drag is expected

Slide 8-2-16

Ask what is wrong in the picture.

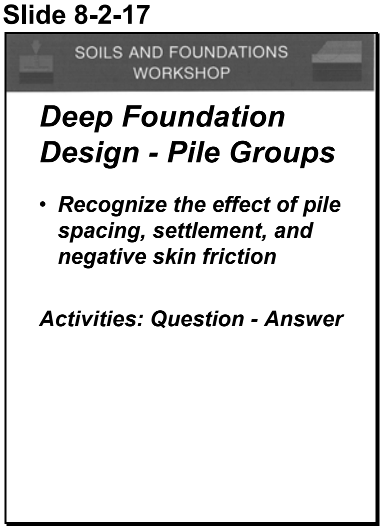
Answer is that the piles were driven upside down; the coated portion of the pile being driven into bearing layer and uncoated portion of the pile into the drag zone. Example of bad communication between design and construction.



Slide 8-2-17

Show Apple Freeway cross section and use to again test learning of deep foundation objectives.

Ask group what potential pile group problems can occur at this site (answer is negative skin friction unless a waiting period to the pile installation).



Slide 8-2-18

Repeat objectives for lesson 8 topic 2.

LESSON 9

TOPIC 1

Construction Monitoring and Quality Assurance – Instrumentation

CONSTRUCTION MONITORING AND QUALITY ASSURANCE

Lesson 9 - Topic 1
Instrumentation

Slide 9-1-1

Header.

CONSTRUCTION MONITORING AND QUALITY ASSURANCE

1. Recall the Basic Types of Geotechnical Instrumentation

ACTIVITY: Question-Answer

Slide 9-1-2

Objectives

Construction Observation and Monitoring

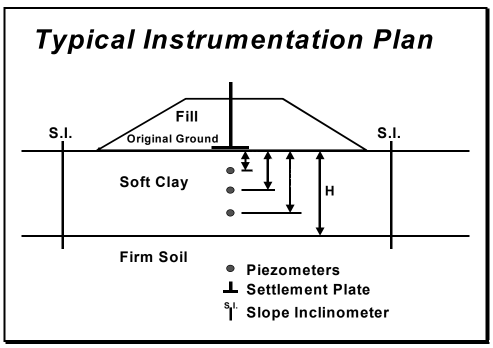
- *Visual*
- *Instrumentation*

Slide 9-1-3

Instrumentation introduction. Instructor should note that some material in this lesson could apply to design as well as construction. The observational method is commonly used in design and construction of highways over soft ground. In these situations the designer realizes that critical conditions may exist which can not be predicted by normal geotechnical analysis and must be dealt with during construction.

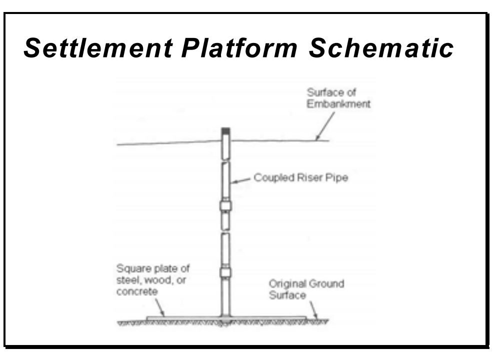
Slide 9-1-4

Case history showing that cracks (visible to the eye) appeared before the instruments detected the problem. Shows importance of trained inspectors.



Slide 9-1-5

Discuss layout of basic pattern and reasons for instrument types. Then show a series of schematics and pictures of common instruments used by geotechnical engineers. Emphasize the importance of instrument selection, installation, reading frequency, and transmittal of data to proper authorities in a timely fashion.

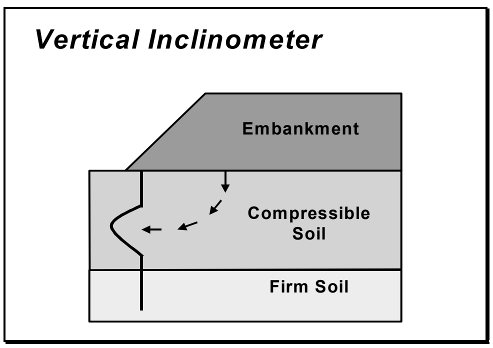


Slide 9-1-6

Basic settlement platform installations consists of a square plate on the original ground attached to a steel pipe. Pipe sections are added as the fill is extended upwards. Advantages are the low cost and the use of optical survey for readings. The disadvantages are the interference with construction and the need for protection against damage.

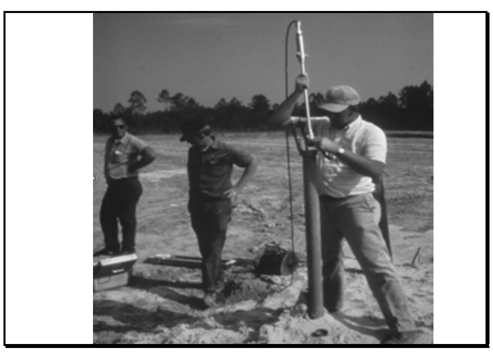
Slide 9-1-7

In the actual installation of a settlement platform, the platform is placed on the original ground surface and the base is covered with a small amount of soil to stabilize the pipe in a vertical position.



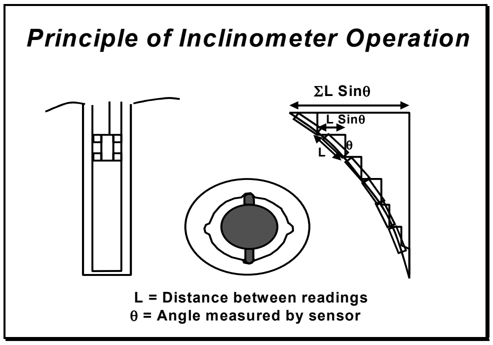
Slide 9-1-8

Schematic of the use of an inclinometer. Although these instruments have several applications, the most popular use is for monitoring lateral ground movements in soft subsoil associated with embankment placement. This is a bread and butter instrument for geotechnical engineers.



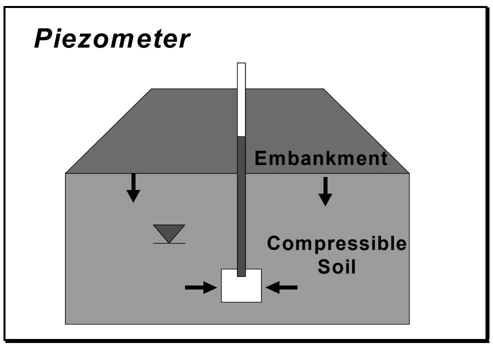
Slide 9-1-9

This is a picture of an in-place inclinometer. The process for installation is to drill a hole through soft soil into a firm base material. The inclinometer casing is then placed in the hole and fixed with grout at the base. The casing for the device is grooved at the quarters point for the entire length of the tube. Casing sections must be accurately coupled to insure groove alignment. The tilt sensor probe is then inserted to the base of the hole and readings taken periodically during withdrawal. Also special features are available such as telescoping casing in situations of large settlement or combination observation well-inclinometer casing.



Slide 9-1-10

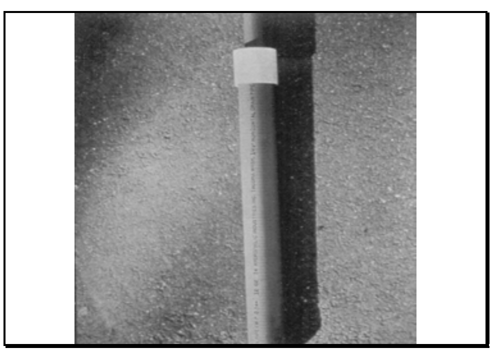
The readings from the tilt sensor device provide a picture of the change in slope of the casing with depth. The probe is inserted in east-west grooves and then north-south grooves to note directional changes in lateral movement. The readings are converted to numerical distance measurements and plotted versus depth to show lateral ground movement. Numerous software programs, such as the IDEAL system from Oregon DOT, have been developed to allow on site review of deflections.



Slide 9-1-11

Schematic of piezometer installation shows the device is used to measure the pore pressure in the ground; generally at more than one depth and at locations where embankment loads are expected to cause large excess pore pressures. Readings are taken periodically after installation to determine the rate of pore pressure decrease.

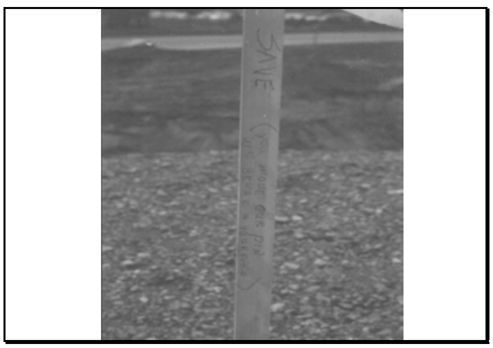
Ask the students what is the result of pore pressure decrease in terms of settlement of the embankment and the strength of the subsoil.


Slide 9-1-12

Different types of piezometers are available which range from a simple open well piezometer to more complex pneumatic or vibrating wire types. Emphasize the importance of instrument selection, installation, reading frequency, and transmittal of data to proper authorities in a timely fashion. These latter types must be carefully inserted in the hole and properly sealed usually by instrumentation specialist. Care should be exercised in selection of the piezometer type, as the response time may be different for rapid increases in pore pressure.

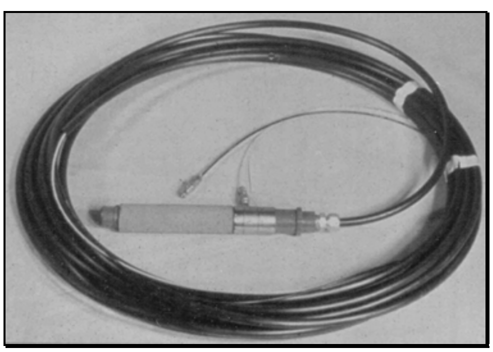
Slide 9-1-13

Basic geotechnical instruments, which are extended up through the embankment need to be protected against damage caused by the contractor's operations. Barriers and/or or flagging are commonly used to alert workers to the presence of instrumentation. Note that the instruments do constrict the work area. Contractors should be apprised of the importance of these instruments in the contract documents and advised that any damage to the instruments will be cause for the engineer to suspend work in that area until the contractor had affected repairs to the damaged instruments.



Slide 9-1-14

Funny slide about an inspector who was frustrated with the contractor continually damaging the instruments located on the embankment grade…left message on stake adjacent to instrument.

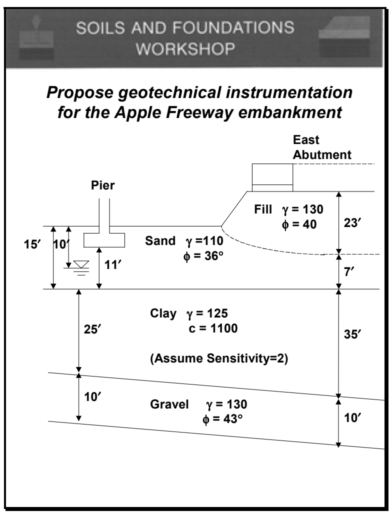


Slide 9-1-15

A better solution is to use remote readouts off the grade. Virtually all geotechnical instrumentation categories have instruments that are suited for remote readout. These instruments have flexible tubes or cables that can be extended under or through embankments.

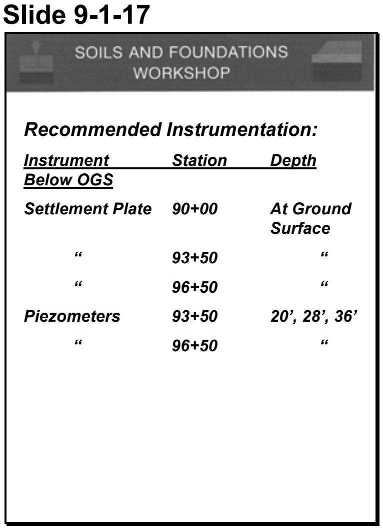
Slide 9-1-16

Most remote readouts for geotechnical instruments are clustered at location off the grade to permit the engineer to easily read all devices from a central location. Recent developments also permit remote reading and automatic transmission of instrument reading via satellite to a central office computer.



Slide 9-1-17

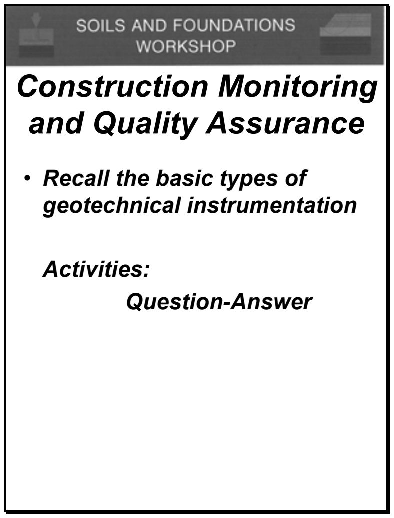
Apple Freeway used as mini-student exercise to test knowledge of geotechnical instruments. Ask the group to recall the issues for settlement and stability for the Apple Freeway and to suggest which geotechnical instruments if any would be recommended for use on the east approach area. (answer is on next overhead).



Slide 9-1-18

Then instructor shows planned Apple Freeway instrumentation and explains reason for instruments (east approach is most critical area for settlement so use both piezometers and settlement platforms). Note that instruments also recommended at west abutment and at end of east approach fill.

Please refer to the Reference Manual page 10-9 for suggested Instrumentation Layout.



Slide 9-1-19

Repeat objectives for lesson 9 topic 1. Then go to the reference manual and overview section 9-2. Alert the group that more information is available in NHI course 132041 on Geotechnical Instrumentation.

LESSON 9

TOPIC 2

Construction Monitoring and Quality Assurance - Foundations

CONSTRUCTION MONITORING AND QUALITY ASSURANCE

Lesson 9 - Topic 2
Foundations

Slide 9-2-1

header

CONSTRUCTION MONITORING AND QUALITY ASSURANCE
Foundations

1. ***Apply Dynamic Analysis to Pile Design***
2. ***Evaluate Pile Equipment Acceptability***

ACTIVITY: Wave Equation Applications

Slide 9-2-2

Objectives

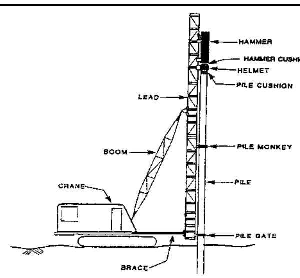
Slide 9-2-3

Comic slide to illustrate crude process of pile driving.

Both the Pile and the Driving Equipment Must Be Sized to Permit Pile Installation to the Designed Length Without Damage

Slide 9-2-4

Introduce concept of matching pile size, equipment size and soil resistance.



Pile Support System

Slide 9-2-5

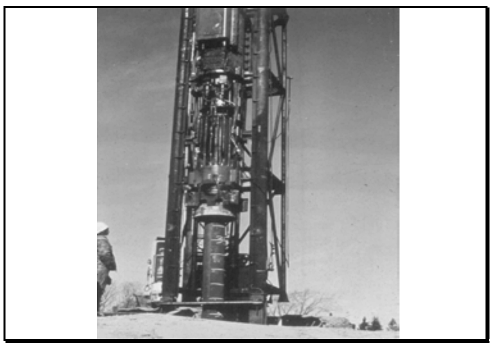
Explain the main elements of the support system that need to be controlled in the specifications and the field. In this session the instructor should thoroughly explain the equipment although some students may already have this basic knowledge. Focus on the leads as a key item that controls the alignment of the hammer-helmet-pile components to insure that each blow of the hammer is concentric to the pile.

Slide 9-2-6

Case histories showing various systems with various degrees of control. This example is a set of "hanging" leads that are not being properly employed as judged by the varying inclinations of the piles that have just been driven. Inspectors need training on such pile equipment to appreciate which equipment is prone to which problems.

Slide 9-2-7

Case histories showing various systems with various degrees of control. In this example a fixed set of leads is holding the pile and the driving system in proper alignment. Point out the alignment of all elements to the group. Also note that the hammer type is an open end diesel hammer.

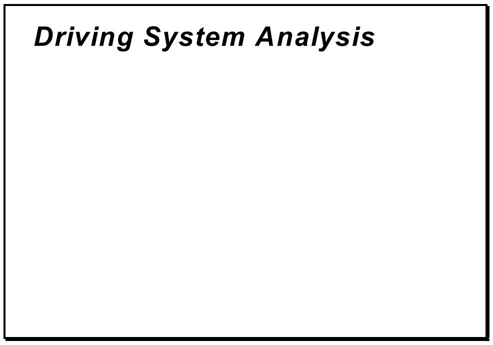


Slide 9-2-8

Case histories showing various systems with various degrees of control. Note the complexity of some of the hammer types that are in used. This is a closed end diesel hammer.

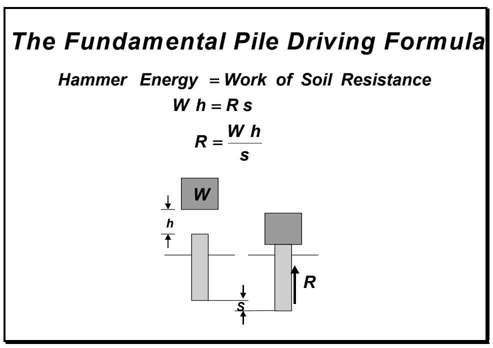
Slide 9-2-9

Case histories showing various systems with various degrees of control. This is vibratory hammer. These hammer are preferred in certain soil types by contractors as the rate of pile penetration can be very fast. However the inspector has no reliable method to determine the capacity of the pile with depth during the installation. Specifications need to include provisions for determining the pile capacity of vibratory driven piles and determining if damage has occurred to the pile.



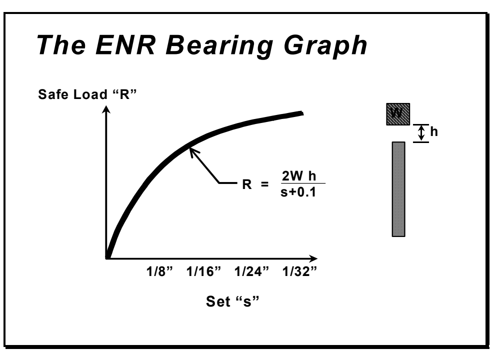
Slide 9-2-10

Introduce driving system analysis. Ask the group why the elements of the driving system are important to control and list answers on a flip chart (answer is that the driving system must be large enough to advance the pile to the desired design depth/capacity and the hammer must not damage the pile).



Slide 9-2-11

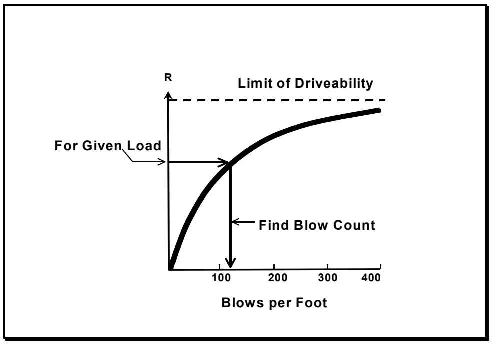
History of dynamic formula for pile control. Relate that this formula was developed in the late 1800's. The concept is that the hammer energy advances the pile a distance s against a resistance R during each hammer blow. If that is correct, then soil resistance can be found if the weight of the ram and the height of drop are known and the set per blow measured. However this formula assumes a Newtonian impact. Anyone who has seen a pile driving operation will quickly realize this is not a Newtonian operation.



Slide 9-2-12

History of dynamic formula for pile control. The ENR formula was developed based on the fundamental concepts and data from numerous pile projects. Note that the term R is the safe pile load as opposed the ultimate pile load in the fundamental formula. The ENR formula gained quick acceptance due to the simplicity of the formula as only the set per blow, s, needed to be measured to find the safe load. ENR remains popular today although subsequent studies showed the hidden safety factor to vary wildly depending on driving equipment and ground conditions.

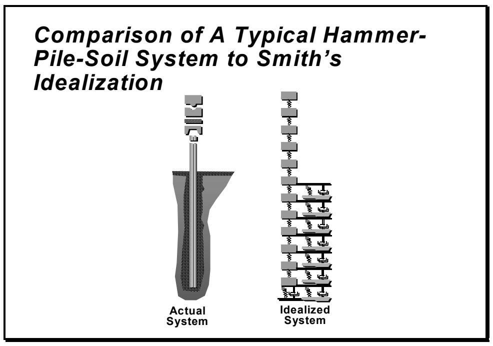
Ask the group what common method of measurement is used instead of set to monitor pile driving (answer is blows per foot which is the reciprocal of the set).



Slide 9-2-13

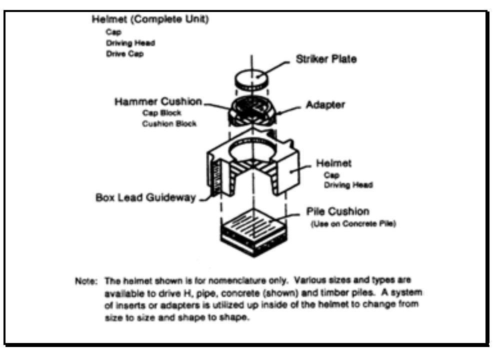
History of dynamic formula for pile control. After the group answers the last question, show this slide as the common method that was used in the past to find the required blow count for an allowable pile design load. However the important point to be made here is that some limit exists as to how deep a pile can be driven in any situation.

Ask the group what are the three elements that control how deep the pile can be driven, (answer is the properties of the hammer, the pile, and the soil).



Slide 9-2-14

Evolution to wave equation improves prediction of capacity. Engineers have realized for many years that pile driving was not a Newtonian problem, but a problem in wave mechanics. The pile wave equation was developed to accounts for the variations in the equipment used for driving, to assess the energy losses in delivering useful energy to the pile, and to account for the losses in energy due to damping effect of the soil. Although not perfect, the wave equation is the best tool the engineer have available to predict pile capacity from hammer blow count.



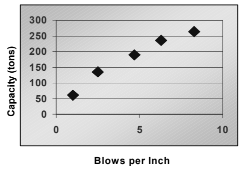
Slide 9-2-15

Explain how important the elements in the drive cap are in relation to the required blow count for pile capacity.

Pile Driving Analysis – Wave Equation Output

14" Square Prestressed Concrete Pile

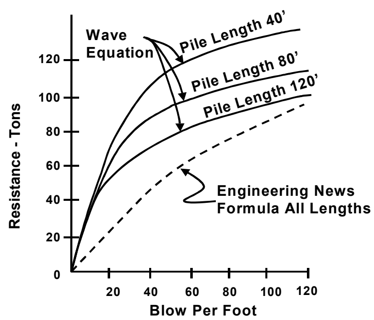
6" Micarta Cap Block, 6" Hardwood Pile Cushion



Blows Per Inch	Capacity (tons)	Max Comp Stress (PSI)	Max Tensile Stress (PSI)
1.0158	61	3738	2394
2.5309	136	3874	1661
4.6649	190	3984	1367
6.3113	236	4036	1208
8.2801	264	4076	1086

Slide 9-2-16

Explain how to read a wave equation output. Note the student exercises to follow will require wave equation output interpretation.



Slide 9-2-17

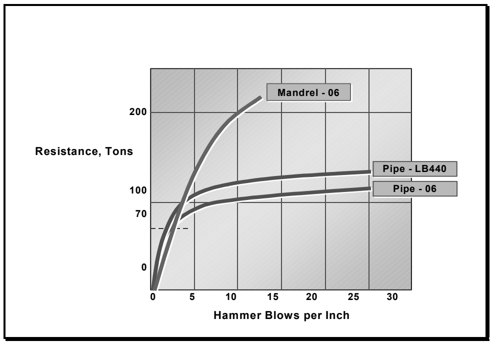
Explain the effect of pile length (stiffness) on blow count.

Pile Mandrels for Shell Piles

- ***Removable pneumatic device for thin wall pile installation***
- ***High stiffness greatly improves driveability***
- ***Requires "doodle hole" for insertion into pile***

Slide 9-2-18

Introduce the concept of improving the stiffness by using a mandrel. Ask who knows what a doodle hole is?



Slide 9-2-19

Show case history of mandrel use. The 70-ton design load pipe piles on this project were to be driven according to an ENR blow count of about 15 blows per inch. The contractor asked to use a mandrel to drive the piles. The project staff agreed as long as the ENR blow count was achieved. The contractor proceeded to drive the piles to three times the estimated length to achieve blow count. Driving was eventually stopped and a load test determined that the piles had in excess of twice the desired capacity. A revised blow count was then determined by wave equation to prevent unnecessary pile overruns.

Slide 9-2-20

Show a second case history of mandrel use. Note that the pile wall thickness needs to be adequate to resist excess pore pressures created by the pile driving. These shells were too thin the resist the pressures and collapsed as soon as the mandrel was removed.

Allowable Stress Levels in Piles

Pile Type	*Allowable Driving Stress*
Steel	*0.9 Fy*
Concrete	*(0.85 F'c – Effective Prestress) In Compression*
	(3 √F'c + Effective Prestress) In Tension
Timber	*3 F'a (Not to Exceed 3000 psi)*

Where: Fy = Yield Strength of Steel
F'c = 28 day Concrete Cylinder Strength
F'a = Allowable Comrpessive Stress of Timber Including Allowance for Treatement Effects

Slide 9-2-21

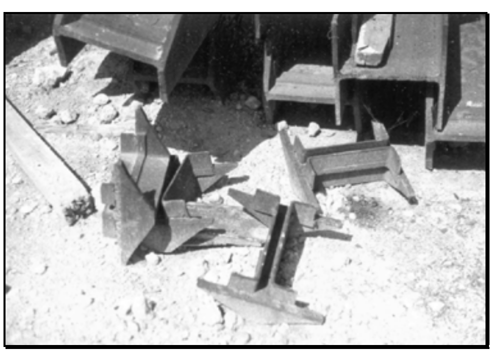
Introduce allowable stress levels for driving pile and clearly differentiate from static stress levels. Note the student exercises to follow will require the use of stress limits.

Slide 9-2-22

Show a few case histories of pile damage. The worst problem is when damage occurs after the pile is below ground. If the damage is detected the pile is usually pulled and a new pile driven. If the damage is not detected the problem may not become evident until structural loads are applied to the pile. The bottom line is that highway agencies need to consider pile overstress caused by the driving operation.

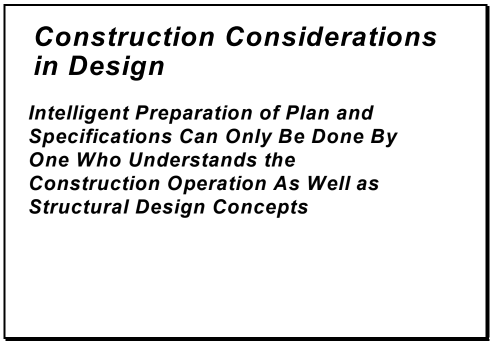
Slide 9-2-23

Show a few case histories of pile damage. The worst problem is when damage occurs after the pile is below ground. If the damage is detected the pile is usually pulled and a new pile driven. If the damage is not detected the problem may not become evident until structural loads are applied to the pile. The bottom line is that highway agencies need to consider pile overstress caused by the driving operation.



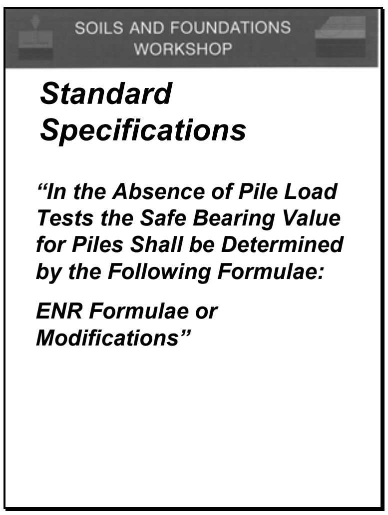
Slide 9-2-24

Mention that the best tip protection are pile points. These points are produced in various shapes and sizes to provide either better penetration or increased end bearing area.



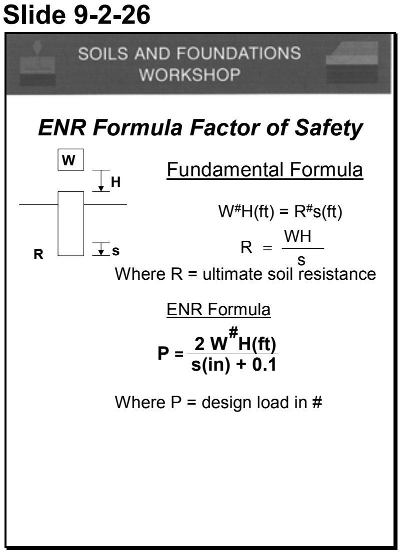
Slide 9-2-25

Emphasize that pile driving must be considered by the designer. Ask students to list properties of the hammer, the pile and the soil, which affect driveability. Instructor writes answer on flip chart.



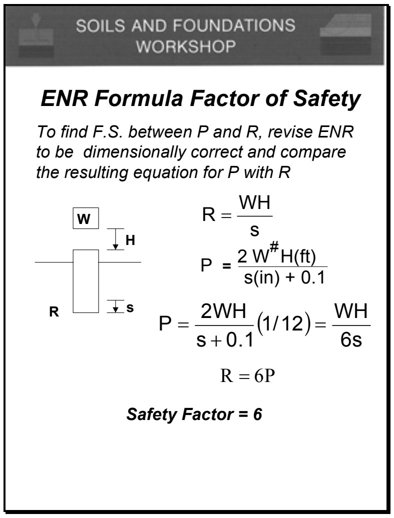
Slide 9-2-26

Review the common use of ENR and the associated problems with the formula.



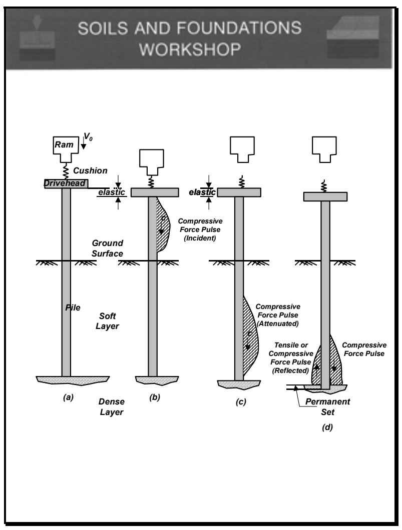
Slide 9-2-27

Instructor, ask students how properties of hammer, pile, and soil written previously on the flip chart, are accounted for by ENR formula (answer is only the hammer energy is accounted for). Then ask what is the built-in safety factor in the ENR formula (6) and derive on next overhead.



Slide 9-2-28

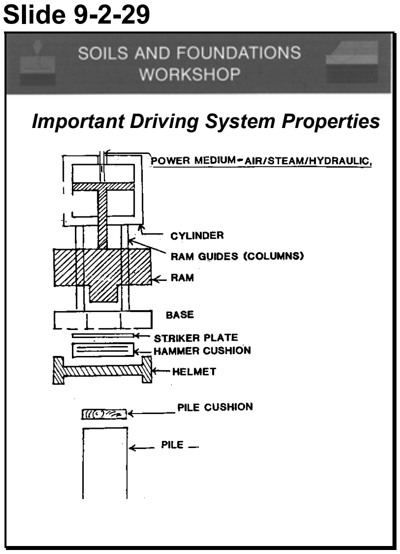
After completing the derivation, ask what is the actual range of safety factor in ENR (answer is 2/3 to 20).



Slide 9-2-29

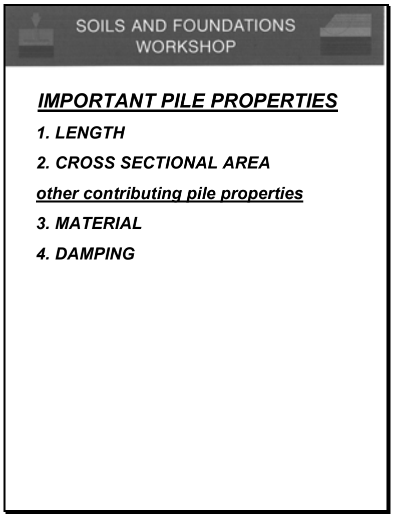
Review how a force wave is generated by the hammer and transmitted down the pile. Note the importance of the amplitude and period of the wave and the damping which occurs in the soil.

Optional: Instructor demonstrates GRLIMAGE program.



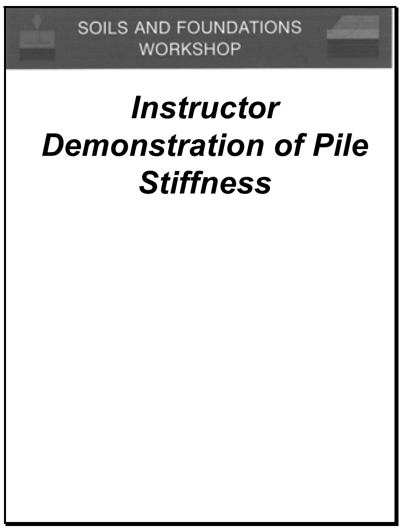
Slide 9-2-30

Instructor asks what information is available to the host agency prior to construction about the hammer that the contractor will use in construction. Note that the elements shown in this overhead will have an influence on the hammer blow count needed to assure the pile load is achieved.



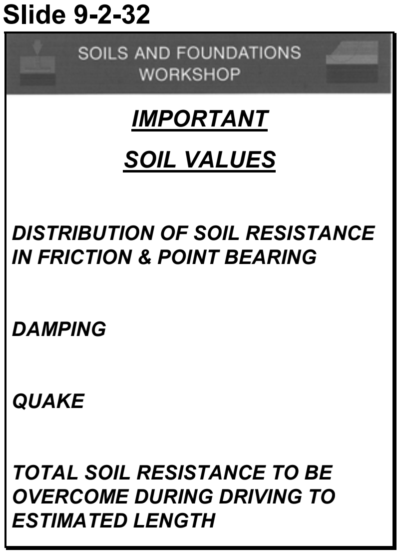
Slide 9-2-31

Review important pile properties. Mention that other properties have a minor effect on pile but are beyond the scope of this course.



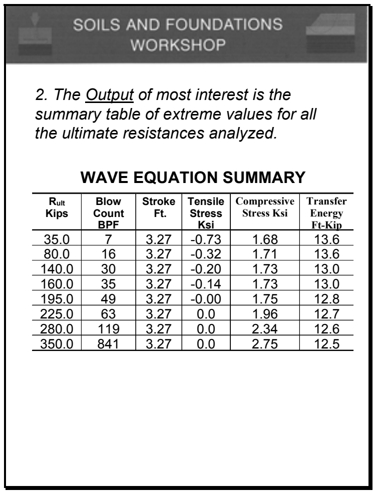
Slide 9-2-32

Instructor then does demo with slender wood dowel and thick wood dowel to show stiffness concept.



Slide 9-2-33

Review important soil properties



SOILS AND FOUNDATIONS WORKSHOP

2. The <u>Output</u> of most interest is the summary table of extreme values for all the ultimate resistances analyzed.

WAVE EQUATION SUMMARY

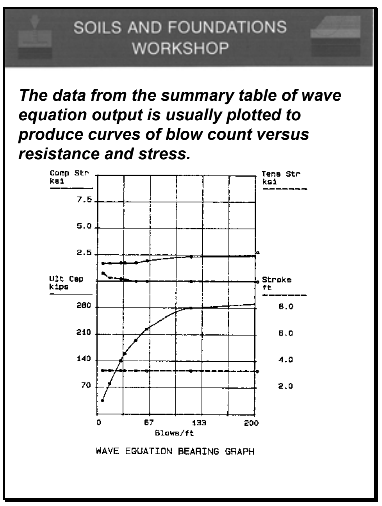
R_{ult} Kips	Blow Count BPF	Stroke Ft.	Tensile Stress Ksi	Compressive Stress Ksi	Transfer Energy Ft-Kip
35.0	7	3.27	-0.73	1.68	13.6
80.0	16	3.27	-0.32	1.71	13.6
140.0	30	3.27	-0.20	1.73	13.0
160.0	35	3.27	-0.14	1.73	13.0
195.0	49	3.27	-0.00	1.75	12.8
225.0	63	3.27	0.0	1.96	12.7
280.0	119	3.27	0.0	2.34	12.6
350.0	841	3.27	0.0	2.75	12.5

Slide 9-2-34

Instructor explains how to read the wave output from the summary table.

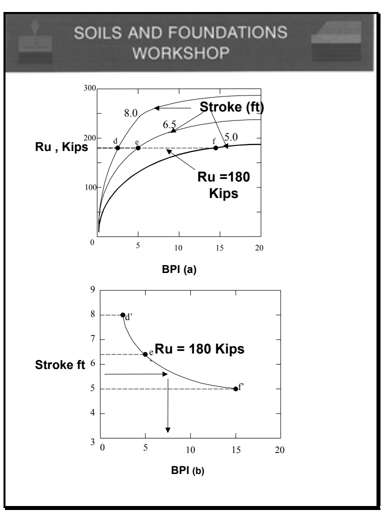
After reading compressive and tensile stresses predicted for the pile, instructor asks if these stresses are within allowable values. The answer is yes. However, point out that a significant tensile stress was noted at a very low driving resistance. If this value was higher than the allowable tensile stress, the designer should perform a supplemental wave equation analysis for a partially embedded pile.

Instructor also asks what type of hammer was used for this example.



Slide 9-2-35

Instructor explains how to read the wave output from the graph of the summary table results.



Slide 9-2-36

Instructor explains difference between diesel and air-steam hammer output.

SOILS AND FOUNDATIONS WORKSHOP

General Criteria for Acceptable Pile Driveability

1. Hammer Blows Between 30-144 per foot
2. Acceptable Driving Stress

Pile Type	Allowable Driving Stress
Steel	0.9 F′ y
Concrete	(0.85 F′c – effective prestress) in compression
	(3 √F′c + effective prestress) in tension
Timber	3 F′a (not to exceed 3000 psi)

Where: Fy = Yield strength of steel
F′c = 28 day concrete cylinder strength
F′a = allowable compressive stress of timber including allowance for treatment effects

Slide 9-2-37

Explain criteria for acceptable driveability of a pile.

Ask students to open reference manual to section 9.3 and review the information that was just covered in the previous slides and overheads for lesson 9-2.

Instructor should now review material in the Reference Manual.

SOILS AND FOUNDATIONS WORKSHOP

Example: Determine If The 14" Square Concrete Pile Can Be Driven To A Driving Capacity Of 225 Kips By Using The Wave Equation Output Summary. Assume The Concrete Compressive Strength Is 4000 psi And The Pile Prestress Force Is 700 psi.

WAVE EQUATION OUTPUT SUMMARY

R_{ult} Kips	Blow Count BPF	Stroke Ft.	Tensile Stress Ksi	Compressive Stress Ksi
35.0	7	3.27	-0.73	1.68
80.0	16	3.27	-0.32	1.71
140.0	30	3.27	-0.20	1.73
160.0	35	3.27	-0.14	1.73
195.0	49	3.27	-0.00	1.75
225.0	63	3.27	0.0	1.96
280.0	119	3.27	0.0	2.34
350.0	841	3.27	0.0	2.75

Slide 9-2-38

Instructor demonstrates use of driveability information in example.

SOILS AND FOUNDATIONS WORKSHOP

Solution:

Acceptable driveability depends on achieving the hammer blows between 30 and 144 at the driving capacity, and assuming that the allowable compressive and tensile driving stress are not exceeded.

1. ***At R_{ult} = 225 Kips, blow count = 63 which is between 30 and 144. O.K.***

2. ***For concrete piles, the allowable driving stresses are:***
   - ***Compressive stress allowed = 0.85 F′c – prestress = 3400 – 700 = 2700 psi, actual Max. compressive stress up to 225 Kips from wave equation output summary is 1.96 ksi or 1960 psi $\leq$ 2700 psi allowed value. O.K.***
   - ***Tensile stress allowed = 3√F′c + prestress = 190 + 700 = 890 psi, actual Max. tensile stress up to 225 Kips from wave equation output summary is 0.730 ksi or 730 psi < 890 psi allowed value. O.K.***

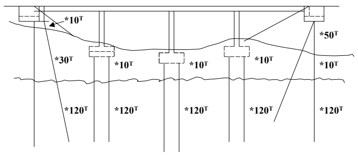
Slide 9-2-39

Instructor demonstrates use of driveability information in example. Explain that although the tensile stress at the drawing resistance of 225 tons is 0 psi, a higher tensile stress may be observed in the pile if either the driving resistance is lower than expected or when the pile is only partially embedded against low resistance. Generally good practice to check tensile force at lower driving resistances.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 8

Design Phase Driveability Analysis



The Profile Shows the Calculated Driving Resistance in Each Soil Layer at Each Footing for the Proposed 12″ Diameter Steel Pipe Piles (Steel F_y = 36 ksi). Using the Maximum Driving Resistance at Any Footing, find the Anticipated Maximum Driving Stress and Blow Count From the Wave Equation Summaries Shown for Three Pile Sizes. Compare These Values to the Recommended Friction Pile Values for Blow Count and Driving Stress to Determine the Minimum Acceptable Pile Wall Thickness for the Pipe Piles at This Site.

Slide 9-2-40

Student pile driveability exercise, which requires use of wave equation output on next overhead. The purpose is to familiarize the students with wave equation output use in design and with the FHWA criteria for acceptable pile driveability. Instructor chooses team to present answer.

Instructor asks group if this stress check is now done in design by the agency.

Please refer to the end of the lesson for this exercise.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 8

GRLWEAP S & F STUDENT EXERCISE 0.250″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	35.3	3.25	-0.85	36.34	14.8
360.0	111.8	3.25	-0.98	42.07	13.8

GRLWEAP S & F STUDENT EXERCISE 0.312″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	31.8	3.25	-0.68	28.58	15.1
360.0	72.9	3.25	-0.70	35.98	14.2

GRLWEAP S & F STUDENT EXERCISE 0.375″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	30.2	3.25	-0.45	24.67	15.2
360.0	58.8	3.25	-0.95	30.47	14.5

Slide 9-2-41

Please refer to the end of the lesson for this exercise.

SOILS AND FOUNDATIONS WORKSHOP

SOLUTION TO EXERCISE NO. 8

		OK	N.G.
Pile 1: 0.250″ wall thickness (9.77 in^2)			
Maximum Stress	42	☐	☒
Blow Count	112	☒	☐
Pile 2: 0.312″ wall thickness (12.19 in^2)			
Maximum Stress	36	☐	☒
Blow Count	73	☒	☐
Pile 3: 0.375″ wall thickness (14.60 in^2)			
Maximum Stress	30.4	☒	☐
Blow Count	59	☒	☐

Select Pile 3, 0.375″ Wall Thickness, Which meets both the Blow Count and Stress Criteria.

Slide 9-2-42

Solution to exercise 8.

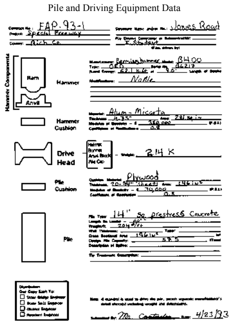
Please refer to the end of the Participant Workbook for the solution to this exercise.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 9
Hammer Approval

The contractor has submitted the pile equipment data form and the wave equation analysis for a 14 ″square prestressed concrete pile (f′c = 5,000 psi and 700 psi prestress) with a design capacity of 115 kips and a driv ing resistance of 300 kips. Should you accept or reject this hammer?

Pile and Driving Equipment Data



Slide 9-2-43

Student hammer approval exercise using the results of wave equation output and the Pile/Driving Equipment Form. Purpose is to familiarize student with the use of the wave equation in construction control and with the typical information submitted by a pile contractor, and to reinforce the FHWA driveability criteria. Instructor chooses team to present answer.

Instructor asks if hammer has reserve capacity to drive pile further than planned without damage.

Please refer to the end of the Participant Workbook for the solution to this exercise.

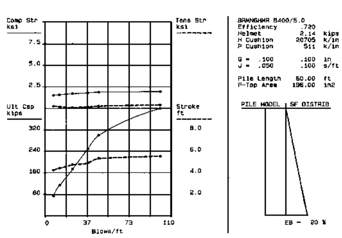
SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 9 (CONT'D)

Federal Highway 01/28/93 GRLWEAP S&F STUDENT EXERCISE HAMMER APPROVAL

Rut kips	Bl Ct bpf	Stroke (ft) down	up	min Str ksi	i,t	max Str ksi	i,t	ENTHRU kip-ft	Bl Rt b/min
75.0	7.2	4.3	4.3	-.30(	7, 19)	1.54(	2, 12)	13.2	56.7
115.0	12.5	4.5	4.5	-.20(	9, 21)	1.62(	2, 12)	11.7	55.3
175.0	24.0	4.8	4.7	-.11(	10, 21)	1.73(	2, 12)	10.1	53.8
250.0	37.3	5.0	5.1	-.19(	9, 30)	1.82(	2, 12)	8.8	52.4
300.0	47.0	5.4	5.3	-.28(	8, 29)	1.90(	2, 12)	8.8	50.9
400.0	102.2	5.6	5.7	-.41(	5, 28)	1.96(	2, 12)	8.1	49.5

G R L W E A P – Federal Highway Admin.
S&F STUDENT EXERCISE HAMMER APPROVAL 01/29/93



Slide 9-2-44

Student exercise wave equation information.

Please refer to the end of the Participant Workbook for the solution to this exercise.

SOILS AND FOUNDATIONS WORKSHOP

SOLUTION TO EXERCISE NO. 9

Acceptable Driving Stresses:
Maximum Compressive Stress = (0.85 × 5,000 psi) – 700 psi = **3,550 psi**
Maximum Tensile Stress = (3 × √5,000 psi) + 700 psi = **912 psi**

Acceptable Blow Count Range: **30-144** blows/foot

Wave Equation Results: 300 Kips Driving Resistance

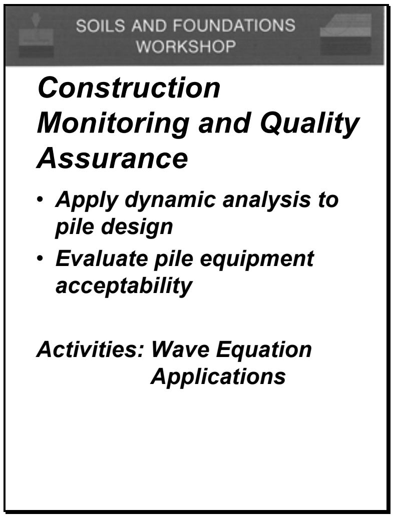
Max (compressive) stress = 1.9 ksi = 1,900 psi < 3,550 psi okay
Min (tensile) stress = -0.28 ksi = -280 psi < -912 psi okay
Blow Count = 47 bpf between 30 & 144 bpf okay

HAMMER APPROVED ✓

Slide 9-2-45

Solution to exercise 9.

Please refer to the end of the Participant Workbook for the solution to this exercise.



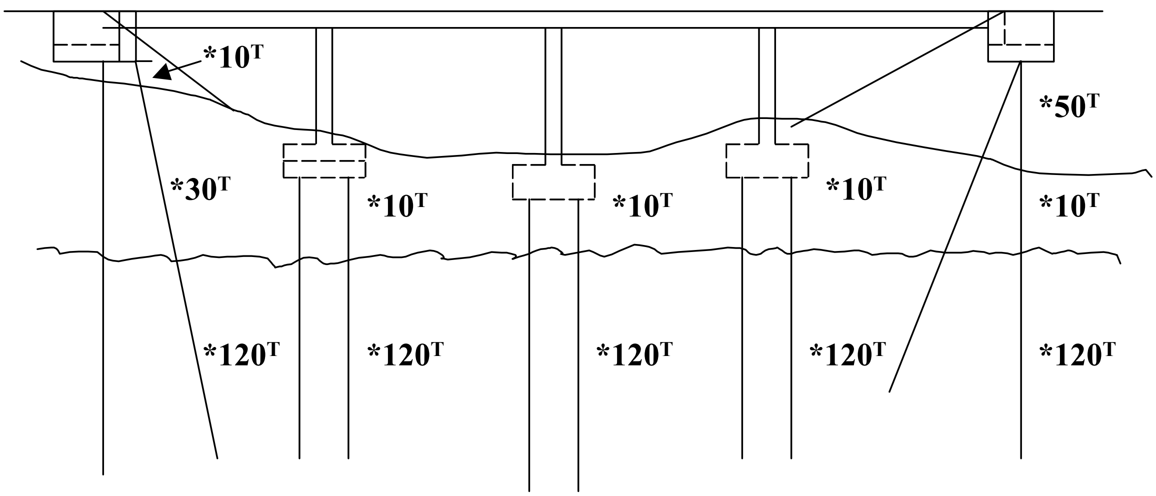
Slide 9-2-46

Repeat objectives for lesson 9 topic 2.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 8

Design Phase Driveability Analysis



The Profile Shows the Calculated Driving Resistance in Each Soil Layer at Each Footing for the Proposed 12″ Diameter Steel Pipe Piles (Steel F_y = 36 ksi). Using the Maximum Driving Resistance at Any Footing, find the Anticipated Maximum Driving Stress and Blow Count From the Wave Equation Summaries Shown for Three Pile Sizes. Compare These Values to the Recommended Friction Pile Values for Blow Count and Driving Stress to Determine the Minimum Acceptable Pile Wall Thickness for the Pipe Piles at This Site.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 8

GRLWEAP S & F STUDENT EXERCISE 0.250″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	35.3	3.25	-0.85	36.34	14.8
360.0	111.8	3.25	-0.98	42.07	13.8

GRLWEAP S & F STUDENT EXERCISE 0.312″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	31.8	3.25	-0.68	28.58	15.1
360.0	72.9	3.25	-0.70	35.98	14.2

GRLWEAP S & F STUDENT EXERCISE 0.375″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	30.2	3.25	-0.45	24.67	15.2
360.0	58.8	3.25	-0.95	30.47	14.5

SOILS AND FOUNDATIONS
WORKSHOP

SOLUTION TO EXERCISE NO. 8

		OK	N.G.
Pile 1: 0.250″ wall thickness (9.77 in^2)			
Maximum Stress	42	☐	☒
Blow Count	112	☒	☐
Pile 2: 0.312″ wall thickness (12.19 in^2)			
Maximum Stress	36	☐	☒
Blow Count	73	☒	☐
Pile 3: 0.375″ wall thickness (14.60 in^2)			
Maximum Stress	30.4	☒	☐
Blow Count	59	☒	☐

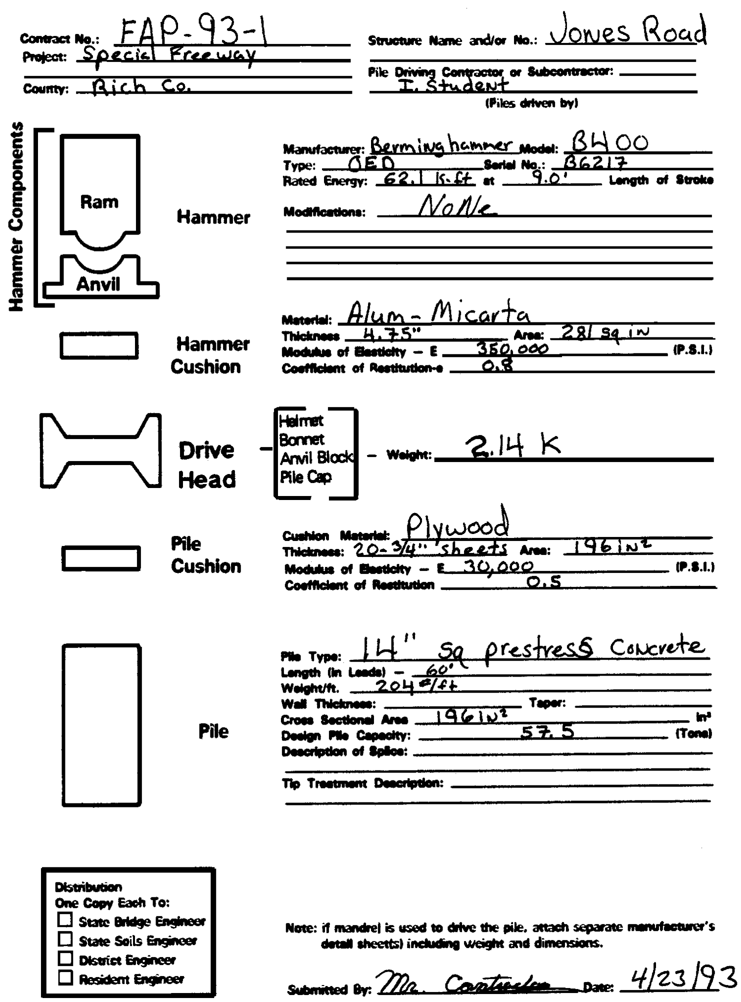
Select Pile 3, 0.375″ Wall Thickness, Which meets both the Blow Count and Stress Criteria.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 9
Hammer Approval

The contractor has submitted the pile equipment data form and the wave equation analysis for a 14 ″square prestressed concrete pile (f′c = 5,000 psi and 700 psi prestress) with a design capacity of 115 kips and a driv ing resistance of 300 kips. Should you accept or reject this hammer?

Pile and Driving Equipment Data



Contract No.: FAP-93-1
Project: Special Freeway
County: Rich Co.
Structure Name and/or No.: Jones Road
Pile Driving Contractor or Subcontractor: I. Student
(Piles driven by)

Hammer Components: Ram, Anvil — Hammer
Manufacturer: Bermingham Model: B400
Type: OED Serial No.: B6217
Rated Energy: 62.1 k-ft at 9.0' Length of Stroke
Modifications: None

Hammer Cushion
Material: Alum-Micarta
Thickness 4.75" Area: 281 sq in
Modulus of Elasticity – E 350,000 (P.S.I.)
Coefficient of Restitution-e 0.8

Drive Head – Helmet / Bonnet / Anvil Block / Pile Cap – Weight: 3.14 K

Pile Cushion
Cushion Material: Plywood
Thickness: 20-3/4" sheets Area: 196 in²
Modulus of Elasticity – E 30,000 (P.S.I.)
Coefficient of Restitution 0.5

Pile
Pile Type: 14" Sq prestress Concrete
Length (In Leads) – 60'
Weight/ft. 204 #/ft
Wall Thickness: Taper:
Cross Sectional Area 196 in² in²
Design Pile Capacity: 57.5 (Tons)
Description of Splice:
Tip Treatment Description:

Distribution
One Copy Each To:
☐ State Bridge Engineer
☐ State Soils Engineer
☐ District Engineer
☐ Resident Engineer

Note: If mandrel is used to drive the pile, attach separate manufacturer's detail sheet(s) including weight and dimensions.

Submitted By: Mr. Contractor Date: 4/23/93

SOILS AND FOUNDATIONS WORKSHOP

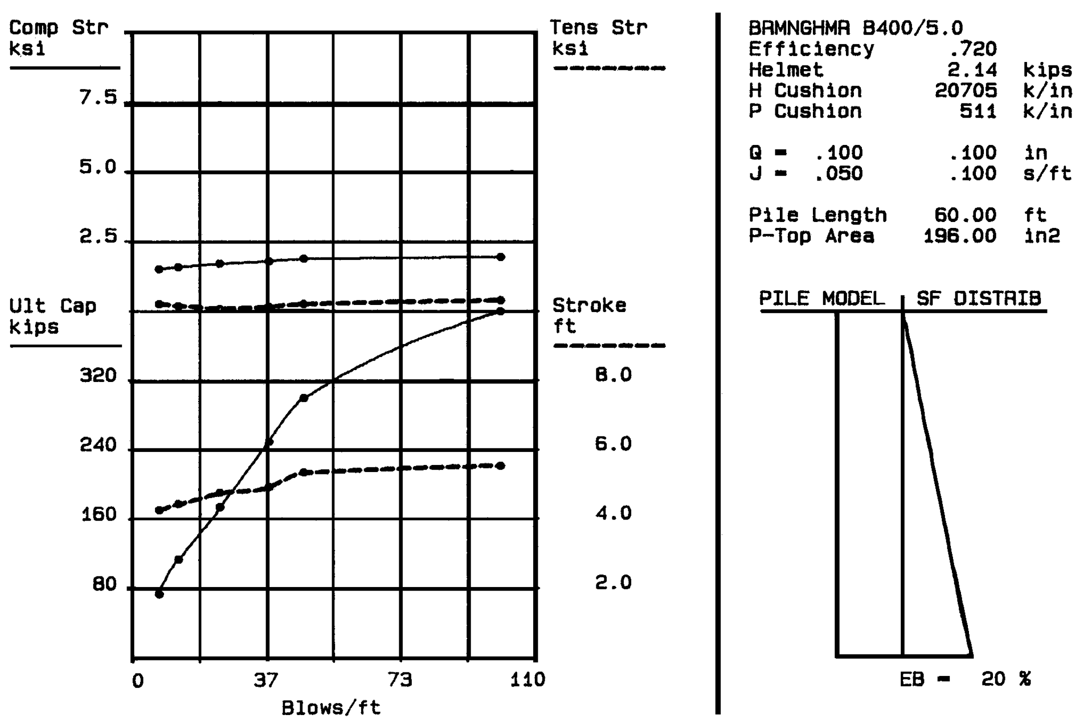
STUDENT EXERCISE NO. 9 (CONT'D)

Federal Highway   01/28/93 GRLWEAP S&F STUDENT EXERCISE HAMMER APPROVAL

Rut kips	Bl Ct bpf	Stroke (ft) down	up	min Str ksi	i,t	max Str ksi	i,t	ENTHRU kip-ft	Bl Rt b/min
75.0	7.2	4.3	4.3	-.30(	7, 19)	1.54(	2, 12)	13.2	56.7
115.0	12.5	4.5	4.5	-.20(	9, 21)	1.62(	2, 12)	11.7	55.3
175.0	24.0	4.8	4.7	-.11(	10, 21)	1.73(	2, 12)	10.1	53.8
250.0	37.3	5.0	5.1	-.19(	9, 30)	1.82(	2, 12)	8.8	52.4
300.0	47.0	5.4	5.3	-.28(	8, 29)	1.90(	2, 12)	8.8	50.9
400.0	102.2	5.6	5.7	-.41(	5, 28)	1.96(	2, 12)	8.1	49.5

G R L W E A P – Federal Highway Admin.

S&F STUDENT EXERCISE HAMMER APPROVAL   01/29/93



SOILS AND FOUNDATIONS WORKSHOP

SOLUTION TO EXERCISE NO. 9

Acceptable Driving Stresses:
Maximum Compressive Stress = (0.85 × 5,000 psi) – 700 psi = **3,550 psi**
Maximum Tensile Stress = (3 × √5,000 psi) + 700 psi = **912 psi**

Acceptable Blow Count Range: **30-144** blows/foot

Wave Equation Results: 300 Kips Driving Resistance

Max (compressive) stress = 1.9 ksi = 1,900 psi < 3,550 psi okay
Min (tensile) stress = -0.28 ksi = -280 psi < -912 psi okay
Blow Count = 47 bpf between 30 & 144 bpf okay

HAMMER APPROVED ✓

LESSON 9

TOPIC 3

Construction Monitoring and Quality Assurance – Pile Load Testing

CONSTRUCTION MONITORING AND QUALITY ASSURANCE

Lesson 9 - Topic 3
Pile Load Testing

Slide 9-3-1

Header

CONSTRUCTION MONITORING AND QUALITY ASSURANCE - Pile Load Testing

1. Relate Pile Load Testing to Design Goals and Cost Savings
2. Interpret Pile Failure Load

ACTIVITIES: Question-Answer
Davisson's Method

Slide 9-3-2

Objectives.

Slide 9-3-3

Funny Slide indicating designers frequently cannot decide on pile length or capacity so they "vote".

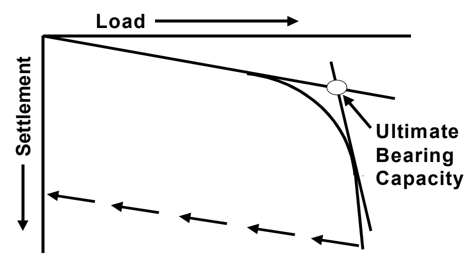
Pile Load Testing

Pile Load Testing is the Most Positive Method of Determining Pile Capacity.

Slide 9-3-4

Introduce the reason for pile load testing.

Load - Settlement Graph



Slide 9-3-5

Show a typical load test plot and interpreted failure load. Use this as the lead to different test procedures may require different interpretation methods for failure.

Types of Load Tests

Routine
- ***Static***
- ***Dynamic***

Recently Developed
- ***Osterberg Cell***
- ***Statnamic***

Slide 9-3-6

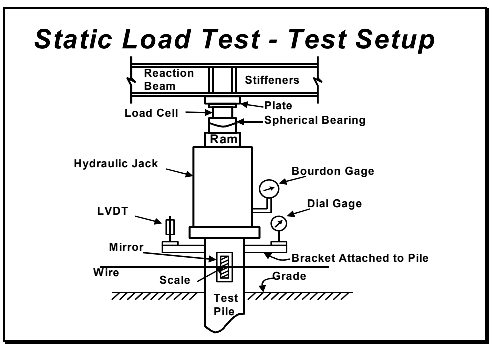
Overview the test types to be covered in the lesson. Differentiate between the common methods and the new methods.

Static Load Test Types
ASTM D1143

- ***Maintained Load***
- ***Quick Load (Texas Quick Test)***
- ***Constant Rate of Penetration (CRP)***

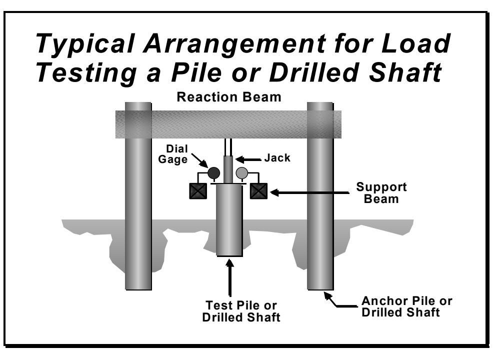
Slide 9-3-7

Overview static load test methods and emphasize that the procedures for these are covered under ASTM.



Slide 9-3-8

The purpose of this slide is to show that the test setup needs to be done by experienced personnel. The amount of test equipment is large and proper placement of instruments critical to the success of the test. In addition the safety of the workers must be respected as loads applied are often very large.



Slide 9-3-9

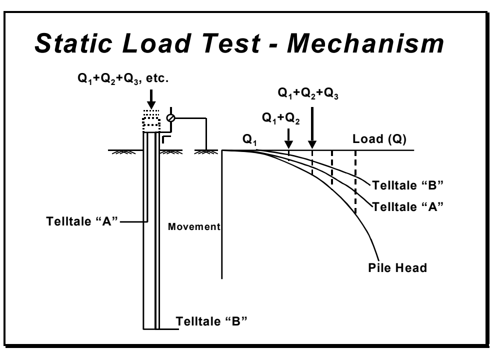
Schematic of a reaction pile setup for a load test.

Slide 9-3-10

Photo of a typical reaction pile setup for a static load test. Note that the time involved to mobilize equipment, drive test pile and reaction piles, build the frame, observe waiting period and run test can be great and represented a delay to the contractor.

Slide 9-3-11

Semi-funny slide about the use of water-filled barges for dead load reaction. Comment is that barges must be covered or wind can cause dangerous water shift that can destabilize barges.



Slide 9-3-12

The static load test involves application of load and measurements of pile movement. Although the test can be completed by measuring only deflection of the pile head, FHWA publications recommend using instruments called telltales to learn more information about transfer of load down the pile. Plots of load versus deflection are made to interpret the failure load and to estimate load transfer at telltale depths.

Dynamic Pile Testing
ASTM D4945

- ***Measures strain and pile acceleration to predict capacity***
- ***Requires experienced personnel to interpret results***
- ***Correlates well with static test results***
- ***Used for time-related capacity changes***

Slide 9-3-13

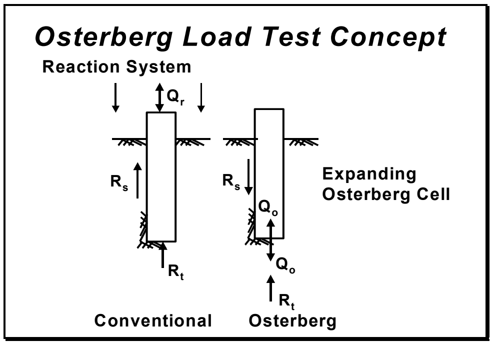
Overview dynamic testing features. Note that the method dates back to the 1970's and the standard was established in 1989. Mention both Pile Dynamic and TNO equipment available.

Slide 9-3-14

Note the strain gage and accelerometer are mounted on the pile during the driving operation. The energy that is delivered to the pile is measured by the instruments and compared to the rated energy of the hammer to evaluate system efficiency. Electrical cables are shown here to transmit the measurements to a field computer but new technology is available for wireless transmission of the signal to the computer.

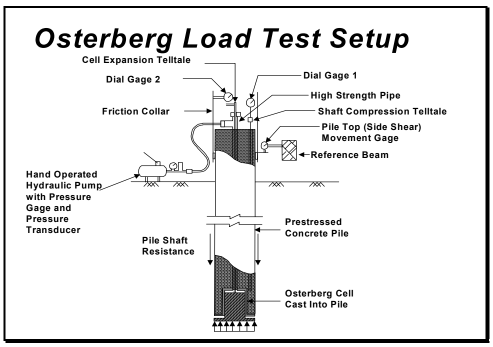
Slide 9-3-15

The dynamic measurements are fed to a small field computer where the data is recorded, processed and results displayed in real time for each hammer blow. The beauty of the system is that the results are available during the pile driving operation to permit the engineer to assess factors such as hammer performance, stresses in the pile, and pile capacity. Data may be collected during both initial driving and after a "setup" period to evaluate changes in pile capacity with time.



Slide 9-3-16

The Osterberg cell test uses a sacrificial load cell which is embedded at or near the tip of the foundation element. The cell is expanded to mobilize both the skin friction and the end bearing of the foundation. Unlike the static test, the Osterberg cell test does not require any external reaction load.

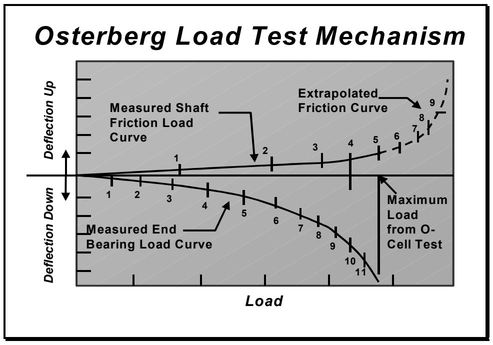


Slide 9-3-17

The Osterberg cell is a proprietary device. The test requires substantial instrumentation and equipment to monitor the response of the foundation to the applied load. The services of specialized load test professionals are needed to setup and run the test. Note that The Osterberg cell test is commonly used for drilled shafts but can also be used for piles.

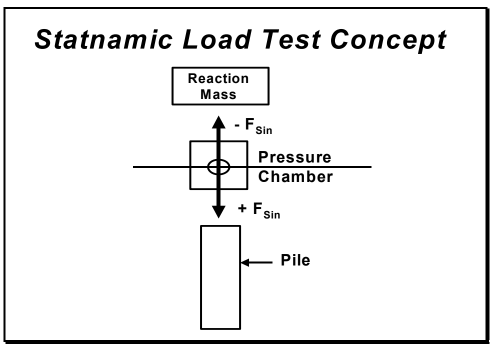
Slide 9-3-18

Example of placement of an Osterberg cell in a drilled shaft at the Boston Central Artery Project. This cell will be positioned 10' above the base of the shaft to equalize predicted end bearing and skin friction forces. The rods below the cell are instrumented with strain gages to show the distribution of load in the socket below the cell.



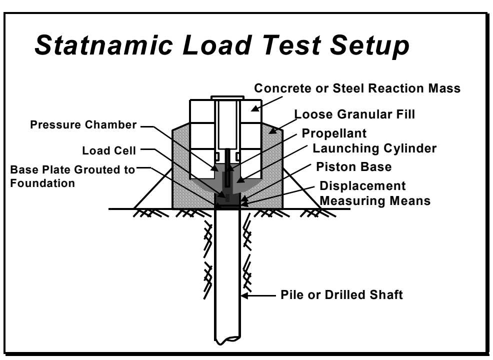
Slide 9-3-19

Osterberg cell test results are plotted on a split load-deflection graph with the skin friction and end bearing resistance shown separately. An important item to note is that the failure load is not achieved for both skin and end bearings during a single stage test. Special techniques, such as the use of cells at multiple locations, are available to refine the ultimate failure load.



Slide 9-3-20

The Statnamic test is a proprietary test method. The concept of the Statnamic test for vertical load capacity is based on a rapid application of load by burning solid fuel in a pressure chamber on top of the foundation. The foundation is accelerated downward.

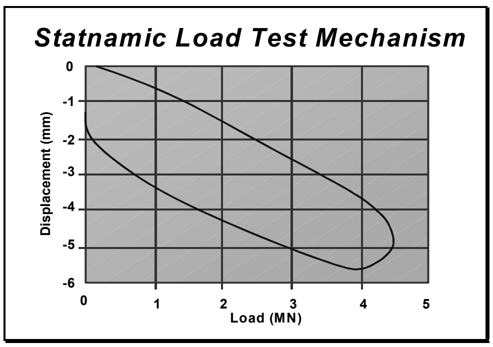


Slide 9-3-21

The setup and conduct of the Statnamic test requires load test specialist. The reaction load can be varied to permit a wide range of load application. The test can be assembled and conducted within minimal timeframes.

Slide 9-3-22

This picture shows the worker assembling the reaction load for Statnamic test. Note the concrete reaction doughnuts are being placed inside the retention structure and over the launching cylinder.



Slide 9-3-23

The data from a Statnamic test is plotted in the typical load-deflection manner for other load tests. However this data includes the effects of the rate of loading and the shaft inertia. Current interpretation procedures use the zero velocity point on the curve to eliminate load rate effects and then subtract the inertia load to find the ultimate static capacity. FHWA purchased a Statnamic device in 1999 for research into the test method and the data interpretation.

Examples of Cost Savings From Pile Load Testing

- ***West Seattle Freeway - Major Project Design Phase Program***
- ***North Carolina DOT - Coordinated Design Phase Programs***
- ***Oregon DOT - Routine Project Test Programs***

Slide 9-3-24

Overview savings, which were achieved by highway agencies, from load testing.

West Seattle Freeway Bridge

Slide 9-3-25

Case history of foundation savings due to load testing on a large project, the West Seattle Freeway, which crosses the Green River and Harbor Island. The bridge was about a mile long and cost about $100 million. The soils, which were generally silts and sands, varied in density and thickness with no bearing layer at a reasonable depth.

West Seattle Freeway Bridge Design

- ***Friction Piles for all Foundations***
  - ***36" Diameter Open-end Pipe Piles for Main Channel Piers (24,000 LF driven)***
  - ***24" Octagonal Prestressed Concrete Piles for Approach Piers (172,000 LF driven)***

Slide 9-3-26

Case history of savings on a large project, the West Seattle Freeway. The results of the load test permitted the main pier piles to be designed for a 600 ton load at lengths about 200'.

Slide 9-3-27

The project used both static and dynamic tests to measure pile capacity at several locations across the site. Note that the static test had extensive telltale instrumentation to permit load transfer measurements in each soil layer. These measurements were used in combination with the boring results at each pier to develop pile lengths for the 80 footing locations.

West Seattle Freeway Bridge

Item	Estimated Saving	Remarks
Piles	$ 9,000,000	-
Pile cap size	$ 1,000,000	-
Test pile data provided to bidders	?	Difficult to quantify savings

Slide 9-3-28

This design load test permitted an increase in the pile design load and therefore reductions in both the number of piles and the cap size. The saving was about 10% of the project cost. All the driving information was provided to the bidders to assist in their estimate of the foundation cost associated with installation of the piles.

North Carolina Design Phase Load Test Programs

Projects 1994-1999	Project Cost $ (Bid)	Test Cost $ (Bid)	Estimated Savings and (%)
Neuse River	92,998,000	310,000	10,500,000 (11)
New River	16,457,000	276,000	850,000 (5)
Chowan River	33,923,000	375,000	1,357,000 (4)
Oregon Inlet	122,800,000	1,155,000	1,200,000 (1)
Croatian Sound	88,963,000	998,000	1,800,000 (2)

Slide 9-3-29

North Carolina DOT published the results of their design phase load test programs in a TRB paper at the 79th meeting in January 1999. The results of the 5 load test programs are summarized above and show substantial savings. The % saving in the parenthesis in the last column is percent of the total project cost.

North Carolina Design Phase Load Test Programs

- **Benefits to Project Design**
  - Reduction in length
  - Increase in capacity
  - Reduced number of piles
  - Driveability, jetting, and set-up evaluated
  - Improved special provisions

Slide 9-3-30

In addition to tabulating the cost savings, the DOT quantified the benefits in terms of improvements to general project design features. Important to note that some improvements benefited future designs.

North Carolina Design Phase Load Test Programs

- ***Benefits to Project Construction***
  - *Improved special provisions*
  - *Restructured pay items*
  - *Eliminated unsatisfactory alternates*
  - *Established dynamic test criteria*
  - *Established pile equipment requirements*
  - *Reduced potential claims*

Slide 9-3-31

The DOT also quantified the benefits of the test programs to project construction. Again some of the improvements had long term implications.

North Carolina Design Phase Load Test Programs

- ***Benefits of new technology verified….***
  - *Pile driving analyser*
  - *Osterberg cell axial test*
  - *Statnamic axial & lateral test*
  - *Integrity test procedures*

….and applied to reduce the costs of subsequent test programs

Slide 9-3-32

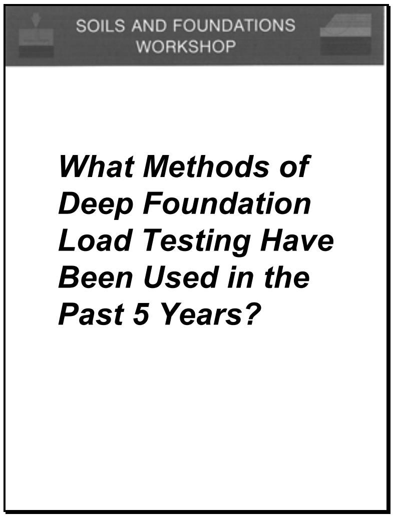
Lastly the DOT decided to independently verify the benefits of new technology in pile load testing in their design phase test programs. New methods were used in conjunction with proven methods to benchmark the performance of the new methods. The DOT developed sufficient confidence in the new methods to be able to apply the new technology independently to subsequent projects; thereby saving time and money in the load testing without sacrificing quality.

Cost Savings for Oregon DOT from Small Project Pile Load Tests

Bridge Location	Pile Size & Type	Length Reduction	Net Savings	Piling Saving
Denny Rd.	12” Sq. Precast Concrete 30’	10’	$55,000	26%
Allen Blvd	12” Sq. Precast Concrete 30’	10’	$60,000	20%
Airport Rd	12¾” Closed end steel pipe 98’	30’	$135,000	25%

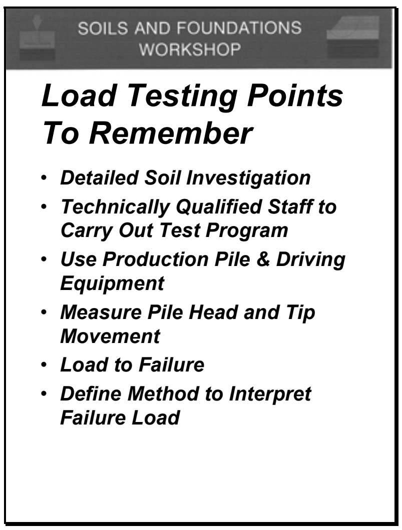
Slide 9-3-33

Oregon DOT demonstrated that a static load test program can be cost-effective on moderately loaded pile types. The total cost of the bridges on these projects were in the $2 million to $4 million range. The savings shown here are as a percentage of the foundation cost.



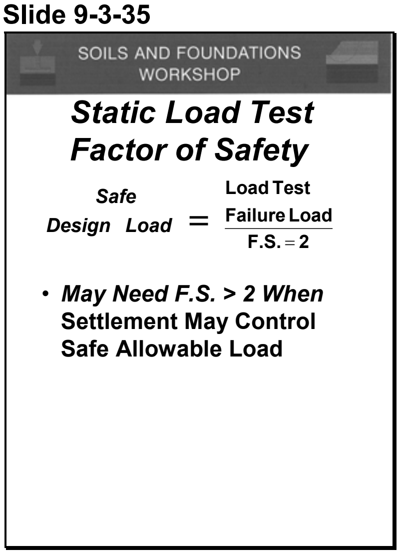
Slide 9-3-34

Instructor lists the answers from the question on a flip chart and discusses how the agency has used load tests (pre-design, construction tests loaded to failure, or construction tests to verify design capacity). This flip chart sheet will be referred to later to ask students questions about their practice for determining when to use, how to interpret failure load, and what safety factor to use in design or how pile lengths are revised in construction based on results.



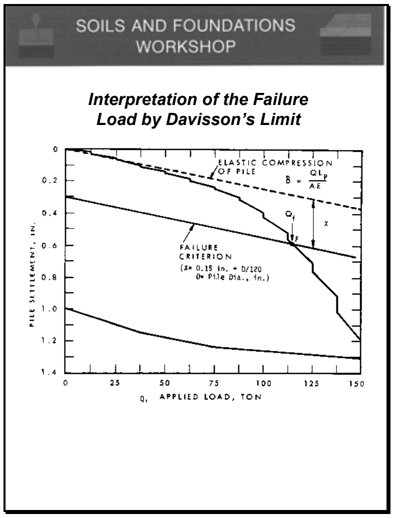
Slide 9-3-35

Show guidelines for load testing. Remind students that these guidelines apply to all types of load testing. Load testing should never be considered a substitute for an adequate site investigation.



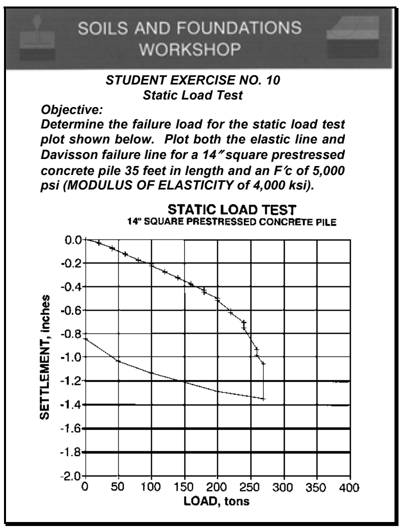
Slide 9-3-36

Instructor returns to previous flip chart sheet and ask group what safety factor is used for each test type shown. Then fill in the missing types covered in the lecture and ask what is the recommended safety factor. Then ask about the safety factor for the case of no testing and just using a formula or wave equation. Ask students to turn to the section in the reference manual for load testing and refer to the subsections on safety factor and the rule of thumb for cost effective testing.



Slide 9-3-37

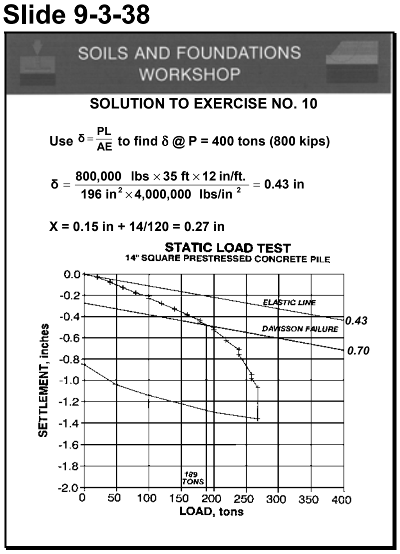
Ask student to turn to the reference manual section on Davisson's method and explain the procedure to find the interpreted failure load by Davisson's method. Mention that they will get a chance to try this method in a student exercise.



Slide 9-3-38

Student exercise to find the failure load by Davisson's method. Purpose of exercise is to learn the necessary data and procedure, which can be used to estimate failure load from a load test. Prepare a flip chart sheet with a rough plot of the load-settlement curve. Then select a group to put up the answer. Ask the remaining groups to refigure the failure load if the criteria was 0.05 inches per ton slope or simply a deflection of 5% of the tip dimension. Then compare results and point out the need to establish the method to interpret failure load; particularly in design-build contracts where the test may serve as the acceptance criteria.

Please refer to the end of the lesson for this exercise.



Slide 9-3-39

Use the overhead as necessary to explain answers to questions about the Davisson method and to show alternate failure interpretation methods. Demonstrate to the group how the length of the pile is affected based on the test results. Relate the change in length to cost in both materials and installation.

Please refer to the end of the Participant Workbook for the solution to this exercise.

SOILS AND FOUNDATIONS WORKSHOP

CONSTRUCTION CONTROL
Pile Load Testing

1. ***Relate pile load testing to design goals and cost savings***
2. ***Interpret pile failure load***

Activity: Question-answer
Davisson's Method

Slide 9-3-40

Repeat objectives for load testing session prior to moving on to the Apple Freeway for the deep foundation lesson closure.

At the instructor's option, the GLRWEAP software may be demonstrated.

SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY

Site Exploration

Basic Soil Properties

Laboratory Testing

Slope Stability

Embankment Settlement

Spread Footing Design

Pile Design

Construction Aspects

Instrumentation
Wave Equation
Hammer Approval

Slide 9-3-41

Show progress of Apple Freeway design and test students on selected information learned in the deep foundations lesson. Remember that the instrumentation information was covered earlier in the session.

SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY

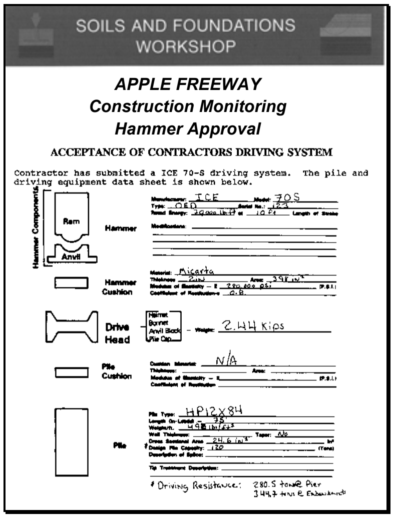
Design Check of Driveability of 12 X 84 H-pile

SUMMARY OF GRLWEAP RESULTS FOR HP12X84 (DELMAG 30-13)

Rut (kips)	Bl Ct (bpf)	Stroke (ft) down	up	min Str (ksi)	i,t	max Str (ksi)	i,t	ENTHRU (kip-ft)	Bl Rt (b/min)
350.0	32.9	6.83	6.70	.00(	1, 0)	29.09(	4, 5)	25.9	45.3
550.0	79.6	7.38	7.32	.00(	1, 0)	31.53(	3, 5)	26.3	43.5
631.8	114.8	7.66	7.44	.00(	1, 0)	32.67(	2, 4)	26.9	42.9
689.4	170.6	7.51	7.47	.00(	1, 0)	32.46(	2, 5)	26.3	43.1
740.0	256.7	7.44	7.49	.00(	1, 0)	32.19(	2, 5)	25.9	43.2

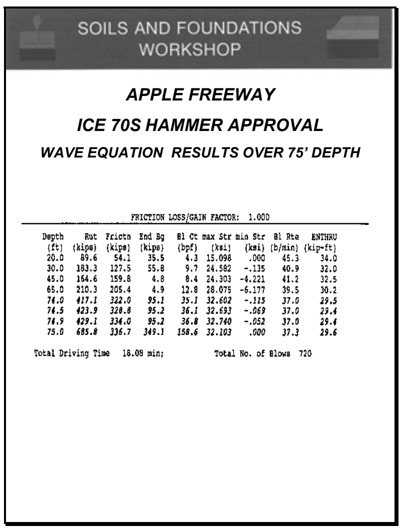
Slide 9-3-42

Ask students to comment on driveability of Apple Freeway H-pile based on current project knowledge and wave output information shown in the overhead of the wave equation output for the maximum pile load.



Slide 9-3-43

Ask students to comment on acceptability of the hammer submitted by the Apple Freeway contractor. First ask what items on this form should be checked (answer is energy if maximum or minimum was specified, type of hammer cushion should be manufactured material, pile cushion if required should be a minimum of 4" thick, pile length and type should match the contract criteria).



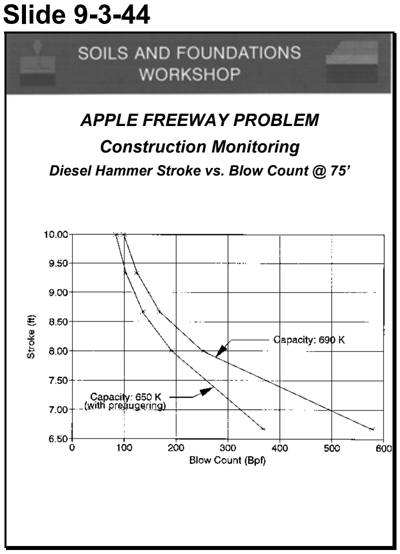
FRICTION LOSS/GAIN FACTOR: 1.000

Depth (ft)	Rut (kips)	Frictn (kips)	End Bg (kips)	Bl Ct (bpf)	max Str (ksi)	min Str (ksi)	Bl Rte (b/min)	ENTHRU (kip-ft)
20.0	89.6	54.1	35.5	4.3	15.098	.000	45.3	34.0
30.0	183.3	127.5	55.8	9.7	24.582	-.135	40.9	32.0
45.0	164.6	159.8	4.8	8.4	24.303	-4.221	41.2	32.5
65.0	210.3	205.4	4.9	12.8	28.075	-6.177	39.5	30.2
74.0	*417.1*	*322.0*	*95.1*	*35.1*	*32.602*	*-.115*	*37.0*	*29.5*
74.5	*423.9*	*328.8*	*95.2*	*36.1*	*32.693*	*-.069*	*37.0*	*29.4*
74.9	*429.1*	*334.0*	*95.2*	*36.8*	*32.740*	*-.052*	*37.0*	*29.4*
75.0	*685.8*	*336.7*	*349.1*	*158.6*	*32.103*	*.000*	*37.3*	*29.6*

Total Driving Time 18.08 min; Total No. of Blows 720

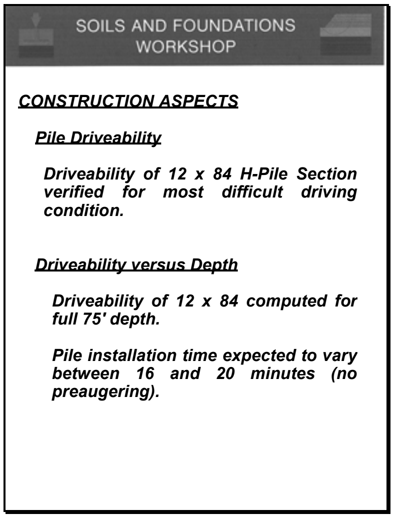
Slide 9-3-44

The second part of the hammer approval process is to determine if the hammer can drive the pile to the estimated length and driving capacity without damage. Ask the students to examine the wave summary and determine if this hammer is acceptable (answer is yes although this is a borderline case. The stresses are near the maximum as is the blow count but only for the last foot of driving. Also this is the most difficult driving condition for all footings on the structure. Need to inform the inspector not to overdrive the pile when rock is reached).



Slide 9-3-45

Ask students how they would interpret this information to determine if a pile was acceptable (answer is to obtain a combination of blow count and stroke within 5' of the estimated length that meets the driving capacity requirement).



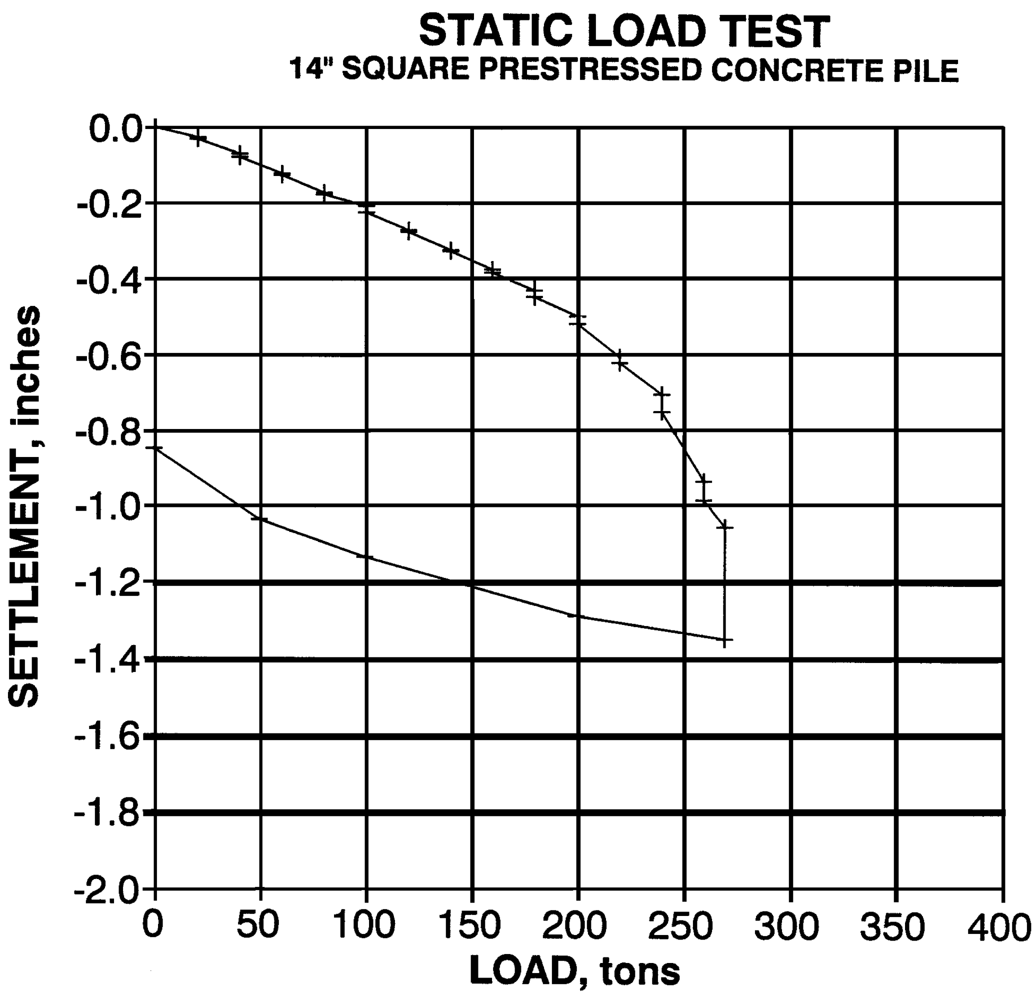
Slide 9-3-46

Review what information was developed for construction portion of the Apple Freeway.

STUDENT EXERCISE NO. 10
Static Load Test

Objective:

Determine the failure load for the static load test plot shown below. Plot both the elastic line and Davisson failure line for a 14″ square prestressed concrete pile 35 feet in length and an F′c of 5,000 psi (MODULUS OF ELASTICITY of 4,000 ksi).



SOILS AND FOUNDATIONS WORKSHOP

SOLUTION TO EXERCISE NO. 10

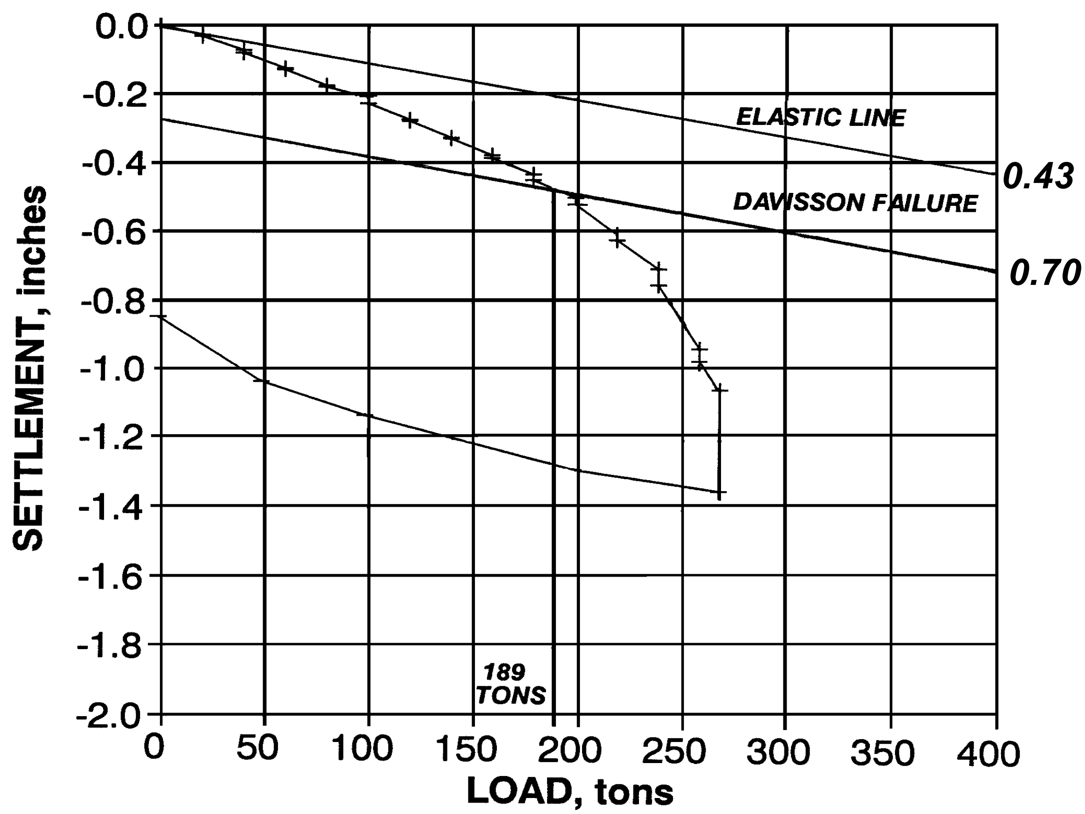
Use $\delta = \frac{PL}{AE}$ to find δ @ P = 400 tons (800 kips)

$$\delta = \frac{800{,}000 \text{ lbs} \times 35 \text{ ft} \times 12 \text{ in/ft.}}{196 \text{ in}^2 \times 4{,}000{,}000 \text{ lbs/in}^2} = 0.43 \text{ in}$$

X = 0.15 in + 14/120 = 0.27 in

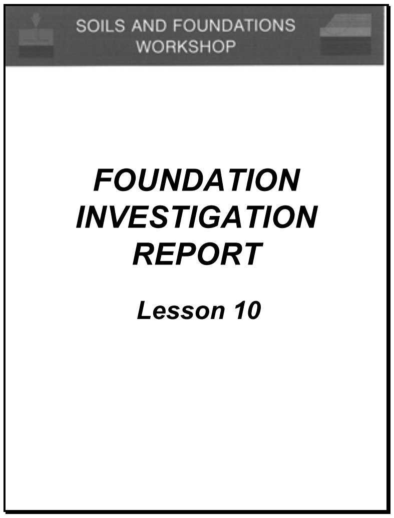
STATIC LOAD TEST

14" SQUARE PRESTRESSED CONCRETE PILE



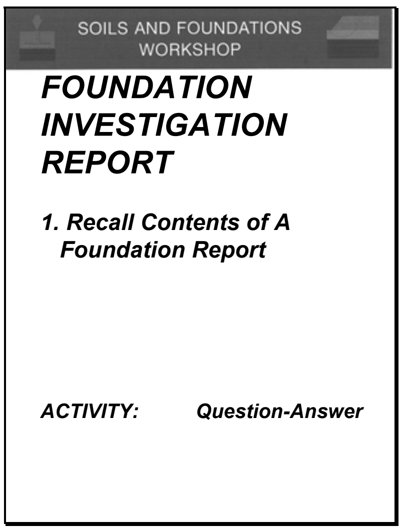
LESSON 10

Foundation Investigation Report



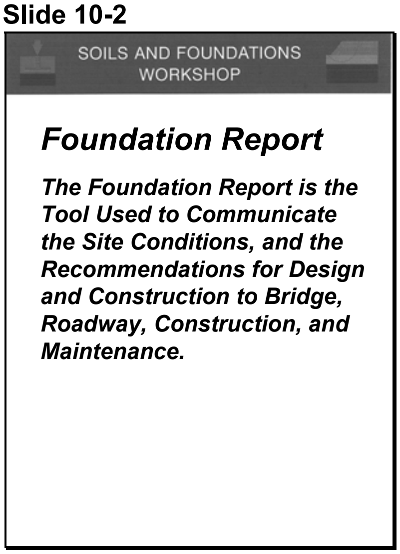
Slide 10-1

Previous to this lesson the highway agency will have presented their procedure for preparation of the foundation report. The instructor should focus and repeat the good elements of what is now done and gently try to improve any negative items during this session.



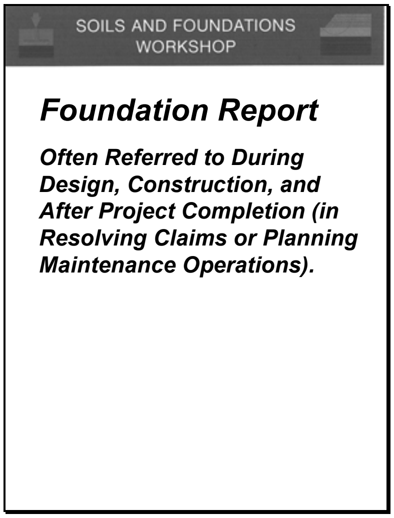
Slide 10-2

Objective



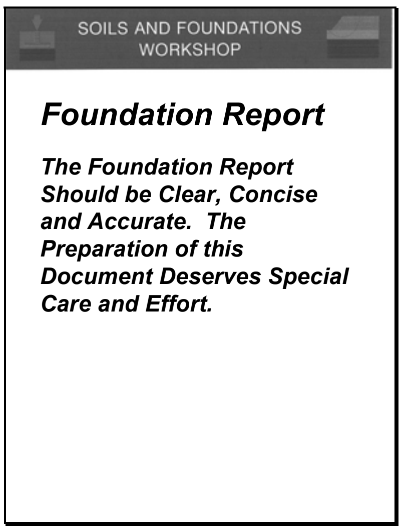
Slide 10-3

Self explanatory overheads to communicate the importance of preparing a good foundation report. These initial overheads summarize the value of an adequate report.



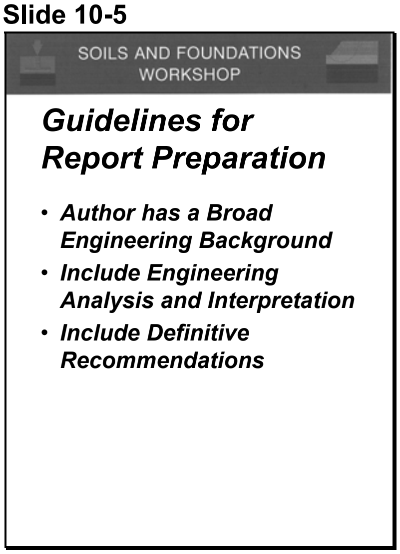
Slide 10-4

Self explanatory overheads to communicate the importance of preparing a good foundation report. These initial overheads summarize the value of an adequate foundation report.



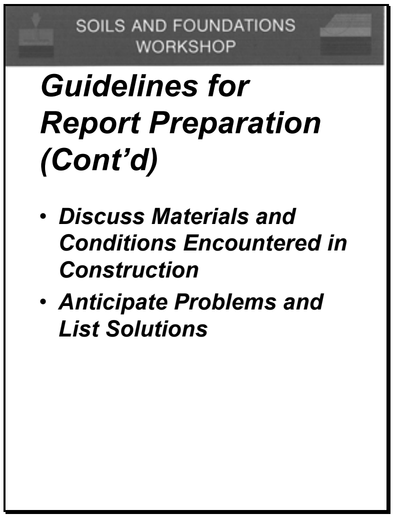
Slide 10-5

Self explanatory overheads to communicate the importance of preparing a good foundation report. These initial overheads summarize the value of an adequate foundation report.



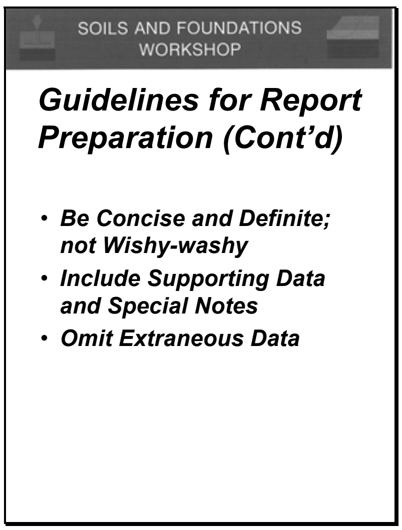
Slide 10-6

The guidelines on these overheads should be discussed but not read verbatim from the visual aid. Important items should be stressed to the group as on this overhead; the need for analysis and interpretation rather than simply displaying the results of the borings. Challenge the group to recognize that engineers are paid to do interpretation, not simply report facts. Instructor should emphasize that consultants for the agency should be required to produce reports which contain the minimum level of information discussed in these guidelines.



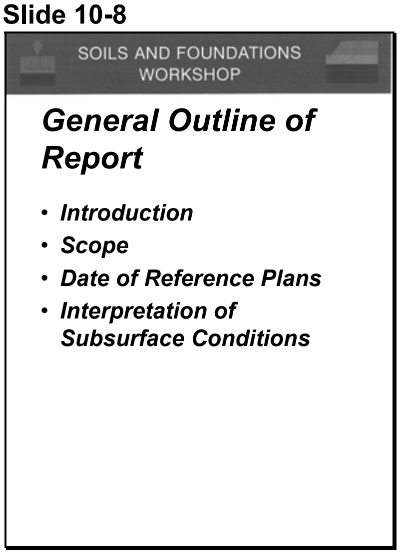
Slide 10-7

The guidelines on these overheads should be discussed but not read verbatim from the visual aids. Important items should be stressed to the group such as on this overhead; the need to consider and evaluate construction items as well as design items. Instructor should emphasize that consultants for the agency should be required to produce reports which contain the minimum level of information discussed in these guidelines.



Slide 10-8

The guidelines on these overheads should be discussed but not read verbatim from the visual aids. Important items should be stressed to the group such as on this overhead; present an example of extraneous data that should not be included. Use the example of a report that contains multiple pages of unrelated geologic information and identifies the minutest detail of every piece of soil and rock to the point where identification of the basic soil or rock type is lost in the verbiage. Instructor should emphasize that consultants for the agency should be required to produce reports which contain the minimum level of information discussed in these guidelines. After this overhead, ask the students to open the reference manual to section 10.1.



Slide 10-9

Self explanatory overheads are now shown to communicate the details of the information that is expected to be included in an adequate foundation report. Ask the group to follow this discussion in the reference manual. Instructor should emphasize that consultants for the agency should be required to produce reports which contain the minimum level of information discussed.

SOILS AND FOUNDATIONS WORKSHOP

General Outline of Report (Cont'd)

- ***Recommendations for:***
  - ***Embankments***
  - ***Foundation Alternates***
  - ***Construction Considerations***
  - ***Special Notes***

Slide 10-10

SOILS AND FOUNDATIONS WORKSHOP

Embankment Considerations

- ***Foundation Settlement***
  - ***Amount and Time***
  - ***Remedial Methods and Costs***
  - ***Downdrag***
  - ***Construction Monitoring***

Slide 10-11

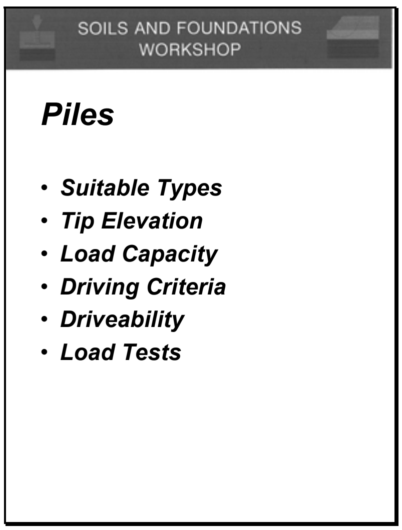
SOILS AND FOUNDATIONS WORKSHOP

Embankment Considerations (Cont'd)

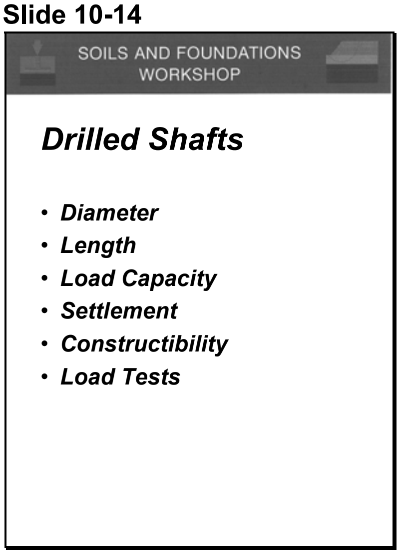
- ***Fill Construction***
  - ***Materials and Construction***
- ***Fill Stability***
  - ***Remedial Measures and Costs***
  - ***Safety Factor***

Slide 10-12

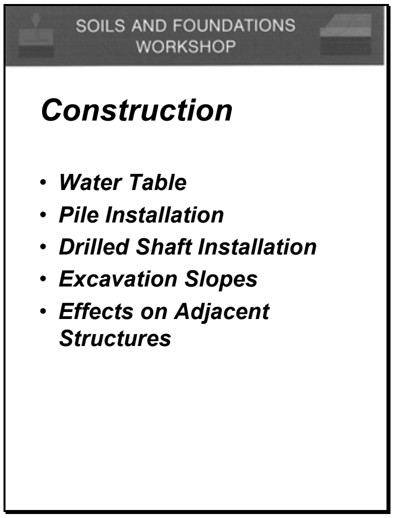
Slide 10-13



Slide 10-14

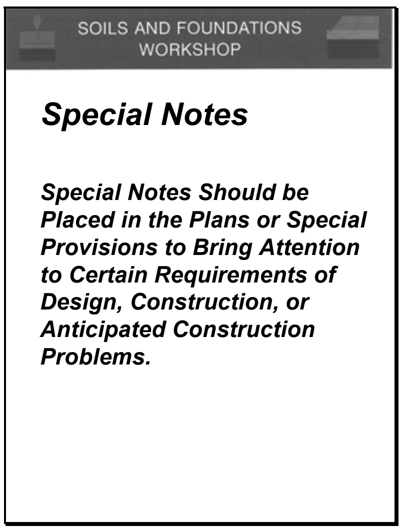


Slide 10-15



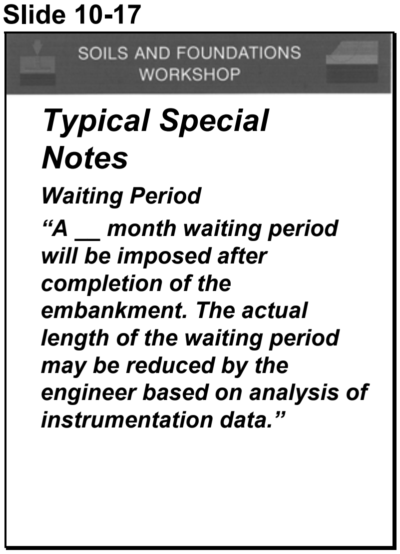
Slide 10-16

After completing discussion of this overhead, ask the group to suggest any other items that should be added to this list.



Slide 10-17

Self explanatory overheads follow to communicate the importance of utilizing special notes. Read of the following notes.



Slide 10-18

Self explanatory overheads follow to communicate the importance of utilizing special notes. Read of the following notes.

SOILS AND FOUNDATIONS WORKSHOP

Typical Special Notes

Cofferdam Dewatering

"The contractor's attention is directed to the soil sample gradation test results, on Drawing __, which are furnished to assist the contractor in determining dewatering procedures."

Slide 10-19

Ask the group how gradation results can help the contractor to assess dewatering requirements (answer is that coarse uniform soils require more pumping than fine well graded soils as noted in the basic soil properties lesson).

SOILS AND FOUNDATIONS WORKSHOP

Typical Special Notes

Construction Instrumentation

"Instrumentation damaged by the contractor shall be repaired or replaced at the contractor's expense. All construction activity in the area of the instrument shall cease until the damage has been corrected."

Slide 10-20

Explain that the effort to replace a settlement platform can involve shutting down a wide area of embankment while excavating to the original ground surface. Contractors do not want such delays and will protect your instruments.

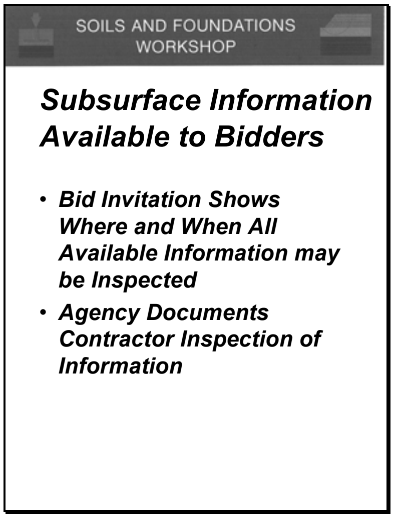
SOILS AND FOUNDATIONS WORKSHOP

Subsurface Information Available to Bidders

- ***Generalized Subsurface Profile or Boring Logs on the Contract Plans***
- ***Lab Test Results & Soil/Rock Samples Made Available for Inspection***

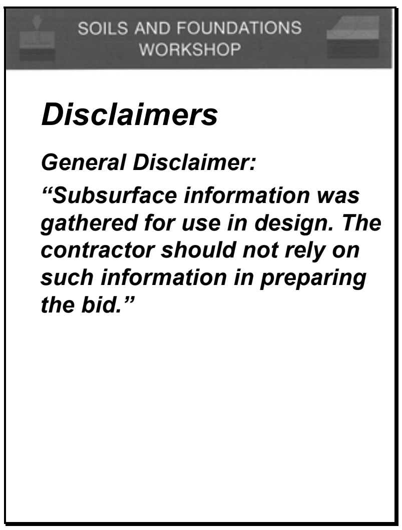
Slide 10-21

Discussion of information made available to bidders. This series of overheads should be used by the instructor to stimulate discussion on the pro and cons of sharing design information with the bidders.



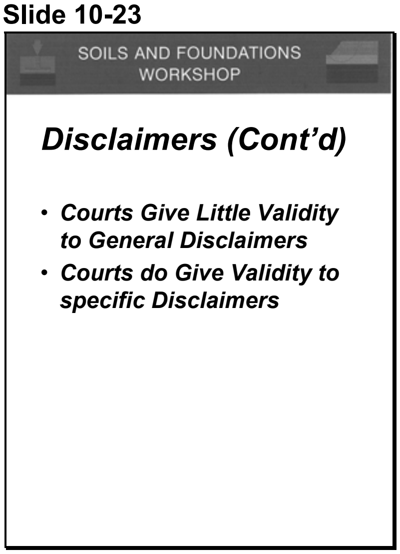
Slide 10-22

Discussion of information made available to bidders. This series of overheads should be used by the instructor to stimulate discussion on the pro and cons of sharing design information with the bidders.



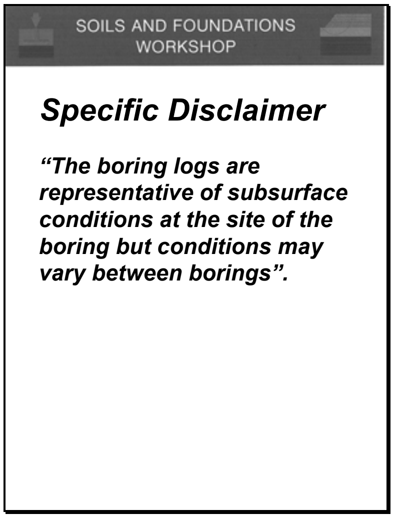
Slide 10-23

Semi-funny overhead which shows that engineers must disclose information which was obtained in good faith about ground conditions. After reading, immediately show next overhead to make point that this type of disclaimer cannot be tolerated.



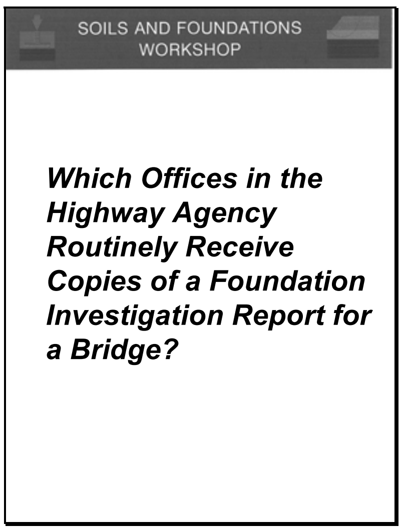
Slide 10-24

Ask the group if they have seen this type of disclaimer used?



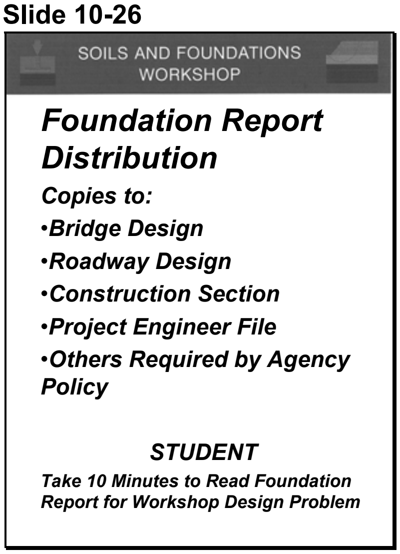
Slide 10-25

Explain that specific disclaimers are valid. Refer group to the reference manual to review the information just covered in the lecture.



Slide 10-26

Hopefully the answer to the question is a wide distribution to many offices. If not, stress how this report is valuable to many offices and recommend future wide dissemination.

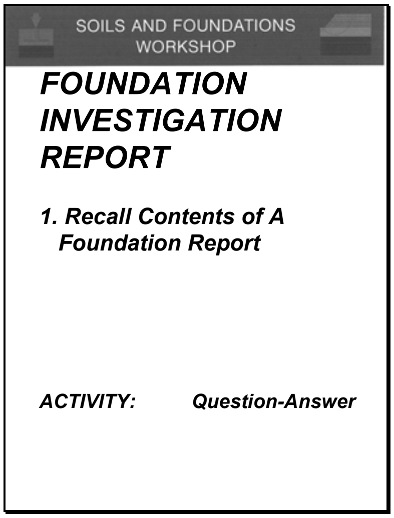


Slide 10-27

Instructor asks students to read report.

Instructor then discusses report with group.

Instructor relates contents of report to overall learning objective.

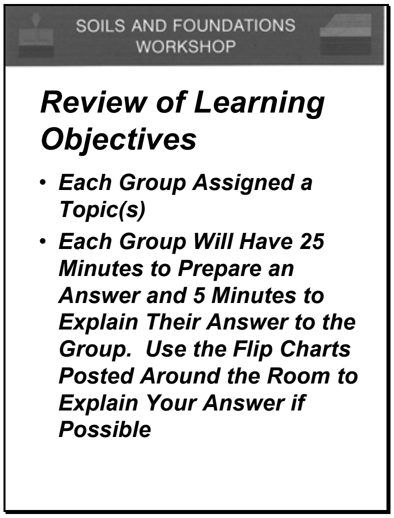


Slide 10-28

Review original learning objective list.

LESSON 11

Review of Learning Objectives


SOILS AND FOUNDATIONS
WORKSHOP
Review of Learning Objectives
• Each Group Assigned a Topic(s)
• Each Group Will Have 25 Minutes to Prepare an Answer and 5 Minutes to Explain Their Answer to the Group. Use the Flip Charts Posted Around the Room to Explain Your Answer if Possible

Slide 11-1