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

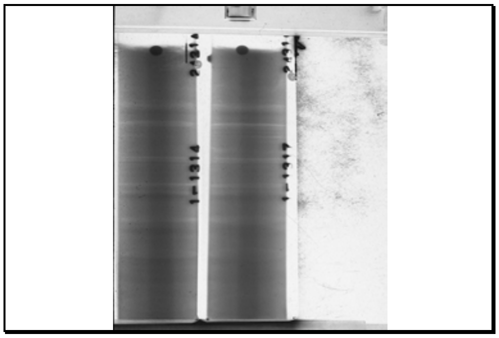
Then undisturbed samples. Point out that the internal structure of the soil sample must be preserved if test results are to be representative of conditions in the soil deposit.

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

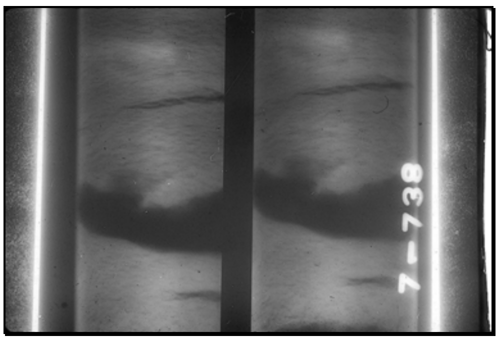
What is the problem with tube storage in the picture? Answer is that the tubes are being stored in a horizontal position rather than vertical.



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

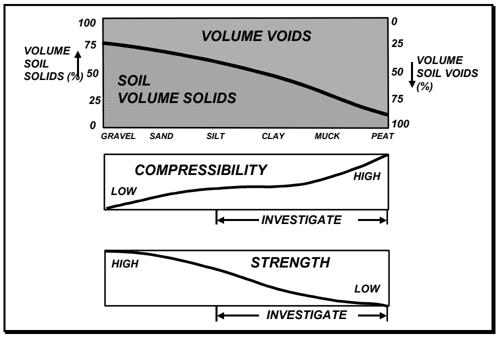
Bad sample.

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

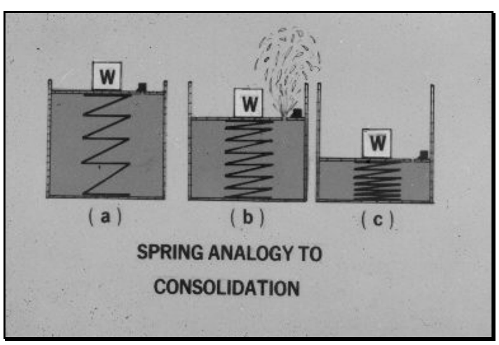
Recall the definition of soil, which involves mineral particles, water and air. Explain that the phase diagram used in this course assumes that the volume of solids represents the mineral particles and the volume of the voids is simplify understanding of basic soil properties and testing concepts.

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

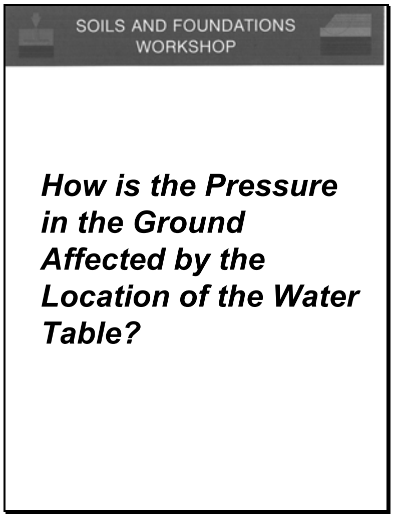
Slide 4-11

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.



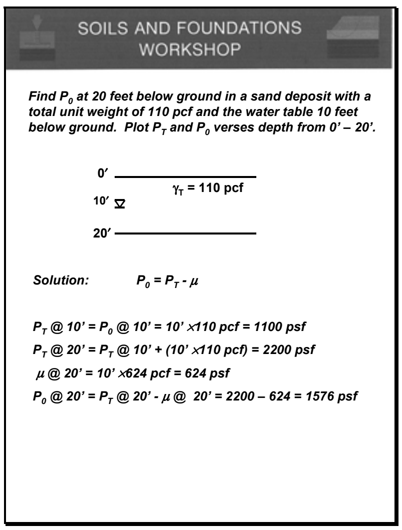
Slide 4-12

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

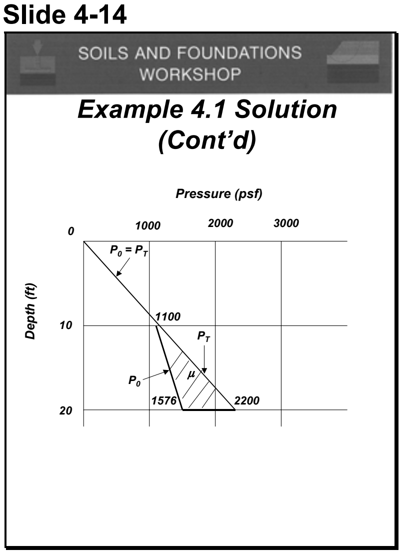
Then show overhead which asks how the position of the water table affects pressure in the ground. After receiving answers from the group, use the previous total pressure overhead to show the water pressure reduces the total pressure to an effective pressure. Write the equation for effective pressure 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.



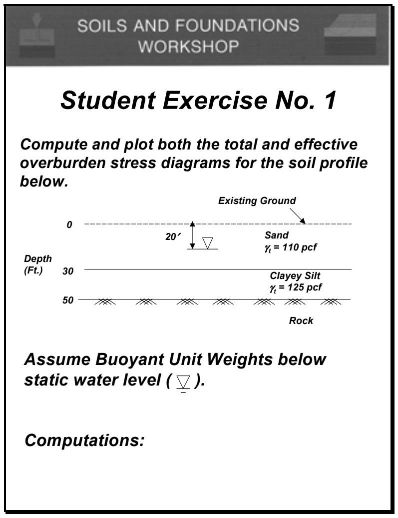
Slide 4-14

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

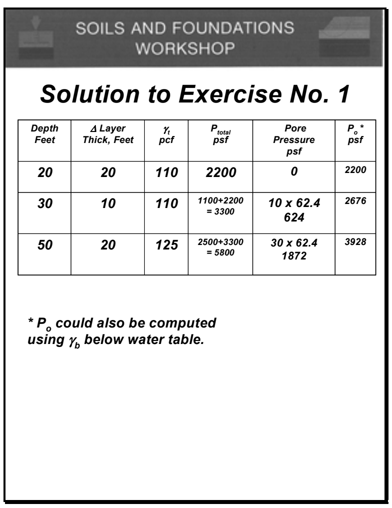


Slide 4-16

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.

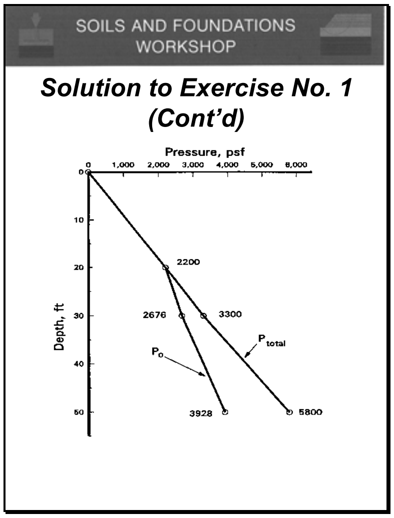


Depth Feet	Δ Layer Thick, Feet	γ_t pcf	P_{total} psf	Pore Pressure psf	P_o* psf
20	20	110	2200	0	2200
30	10	110	1100+2200 = 3300	10 x 62.4 624	2676
50	20	125	2500+3300 = 5800	30 x 62.4 1872	3928

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

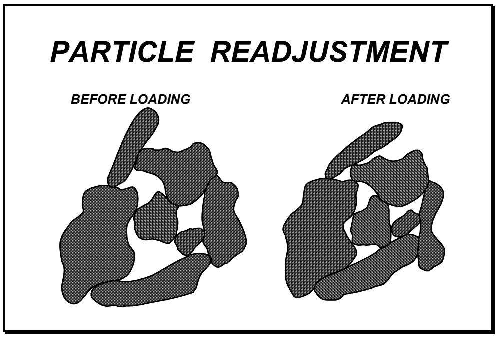
Consolidation

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.

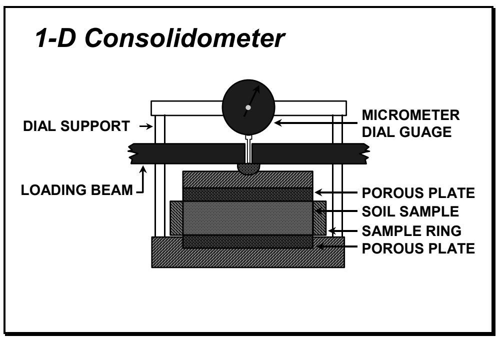
Slide 4-20

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.



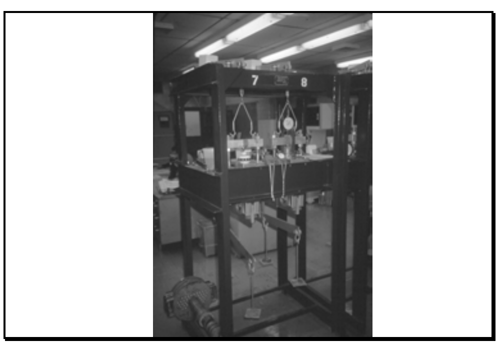
Slide 4-21

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.

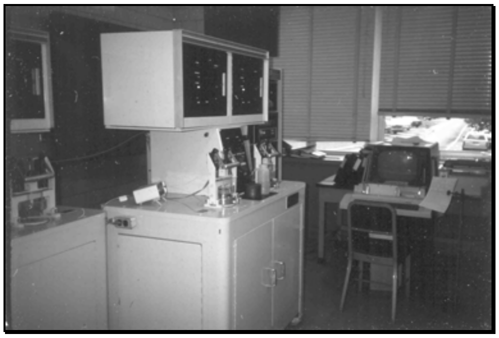


Slide 4-23

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

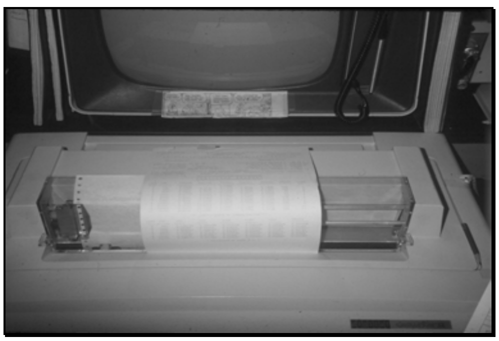
A typical basic manual apparatus is shown here. Note the lever arm and weights which are used to apply high pressure to the small soil sample. Typical maximum test loads are in the order of 32 tons per square foot.

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



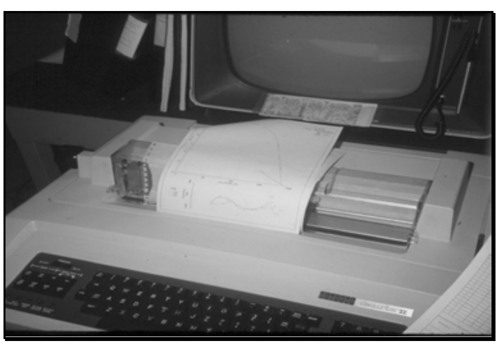
Slide 4-24

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



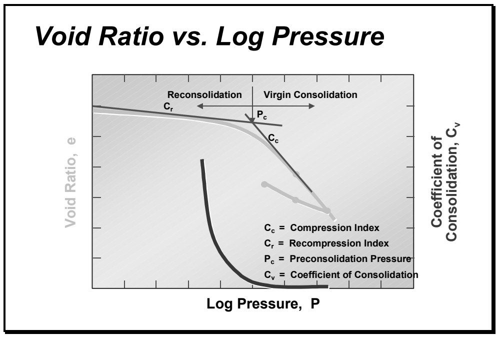
Slide 4-25

Show computerized computations.



Slide 4-26

Show computerized plotting feature.



Slide 4-27

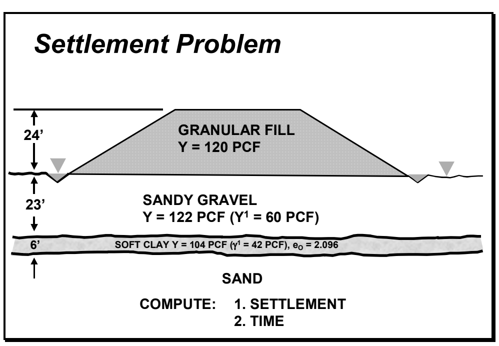
Explain the e-log P plot and how to extract pertinent information. Focus particularly on compression and recompression indices and the preconsolidation pressure. Mention that other plots are used to find the coefficient of consolidation and estimate the drainage rate. Refer to the position of the C_v – 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.

Effects of Sample Disturbance on Consolidation Test Results

- ***Eliminates Break in e-log P Curve***
- ***Lowers Measured Values of P_c and C_c***
- ***Lowers Measured Value of C_v***
- ***Increases Measured Value of C_r***

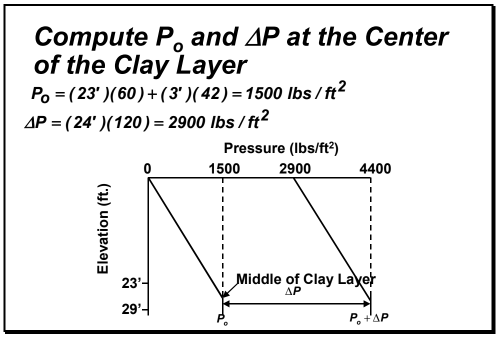
Slide 4-28

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



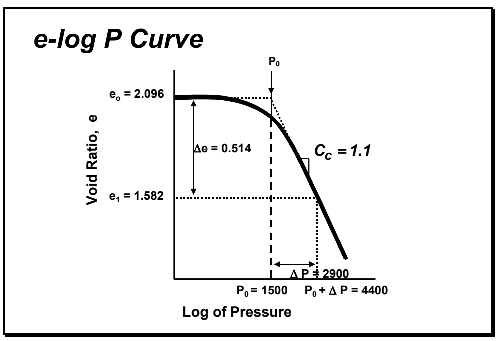
Slide 4-29

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.



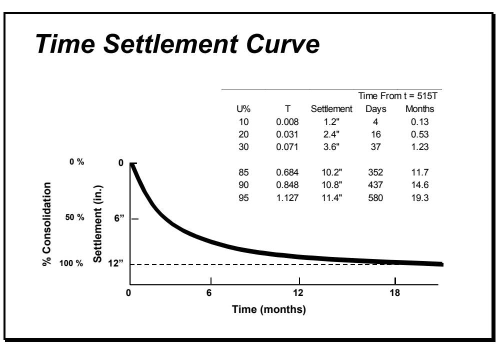
Slide 4-30

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



Slide 4-31

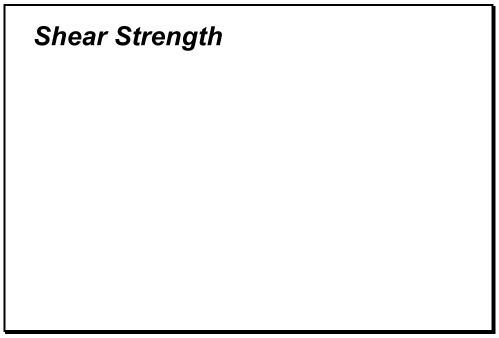
Explain how test data used in computation. Note that the e-log P plot is entered with P_o and P_f pressure to find the change in voids ratio, e, due to the applied load. This change is directly related to the amount of settlement.



			Time From t = 515T	
U%	T	Settlement	Days	Months
10	0.008	1.2"	4	0.13
20	0.031	2.4"	16	0.53
30	0.071	3.6"	37	1.23
85	0.684	10.2"	352	11.7
90	0.848	10.8"	437	14.6
95	1.127	11.4"	580	19.3

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.



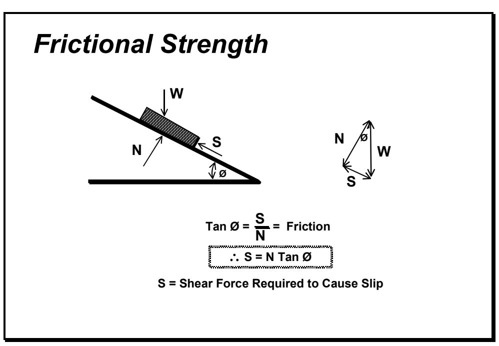
Slide 4-33

Introduce shear strength.

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

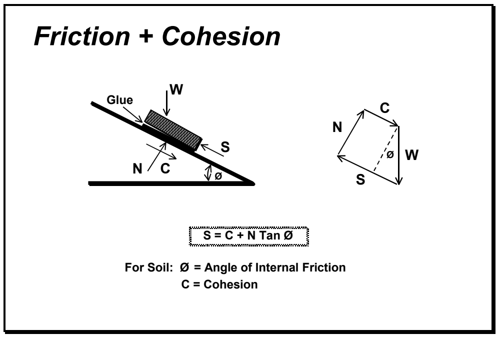
Slide 4-34

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.

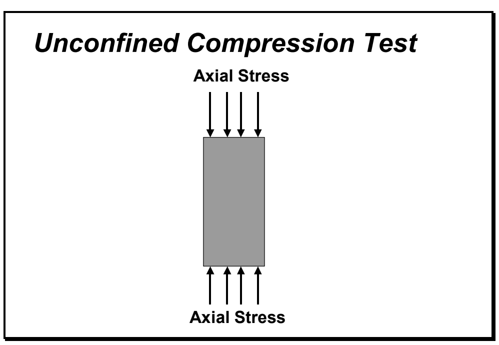
Typical Methods of Shear Strength Testing

- ***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

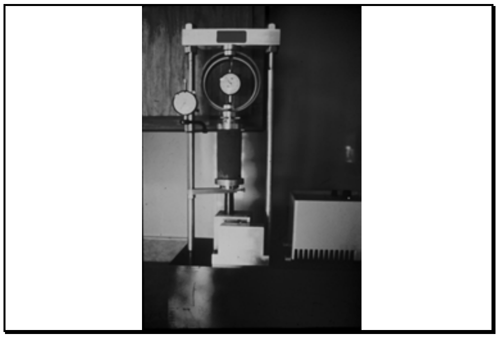
List types of strength testing. Ask students what acronyms mean. The answer is the consolidation state prior to shear and the drainage during shear.

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.



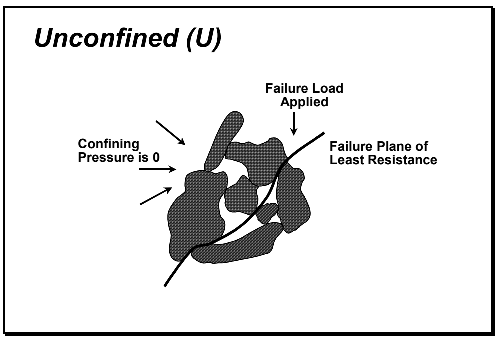
Slide 4-38

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



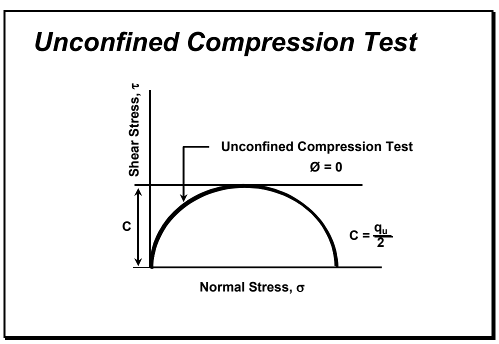
Slide 4-39

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

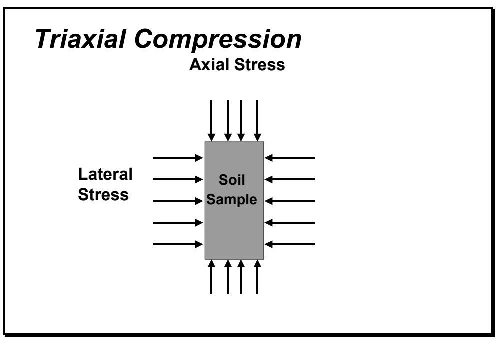
Note that the results of an unconfined test are commonly presented to the designer in the form of a Mohr diagram with the circle originating at the zero axis. The test result is the cohesion. Ask students why a frictional strength is not reported. Answer is N=0. Therefore friction is 0.

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***

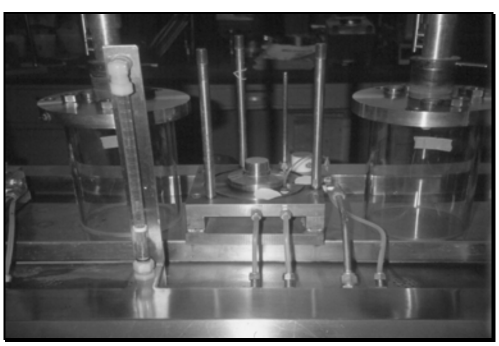
Slide 4-42

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.



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.

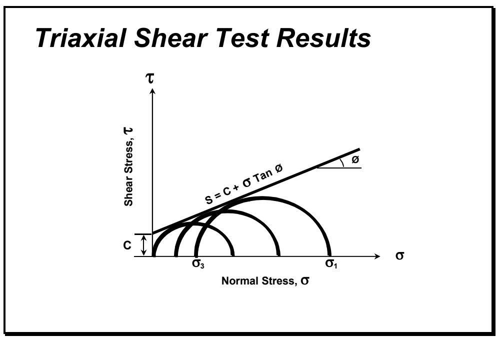


Slide 4-44

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.

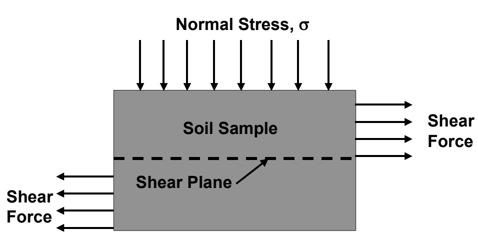
Consolidated Drained (CD) Triaxial Compression Test

- ***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

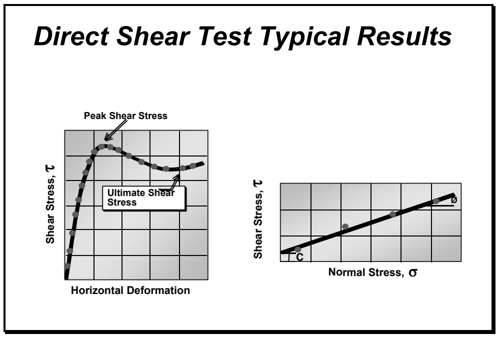
Also performed on multiple samples. CD test equipment is designed to accommodate very low strain rates. Such strain rates are needed to prevent the development of excess pore pressures in the sample during testing. The test results are represented as a drained friction angle and a small cohesion value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



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

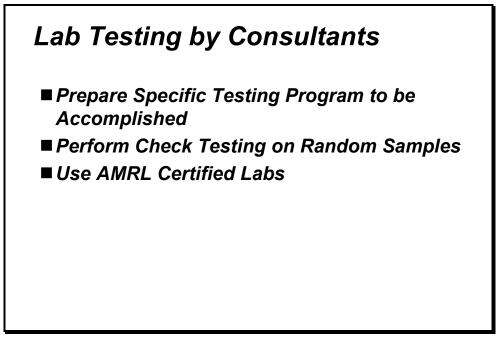
Direct shear test equipment is low cost and can handle granular soil particle sizes up to 0.1”. The results of the test are generally reported as a friction angle. More sophisticated direct shear equipment is available to perform tests on larger particle sizes or to test interface friction with non-soil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

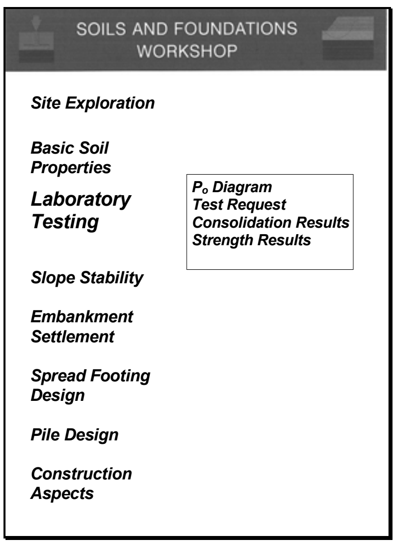
Slide 4-53

Review basic minimum lab guidelines.



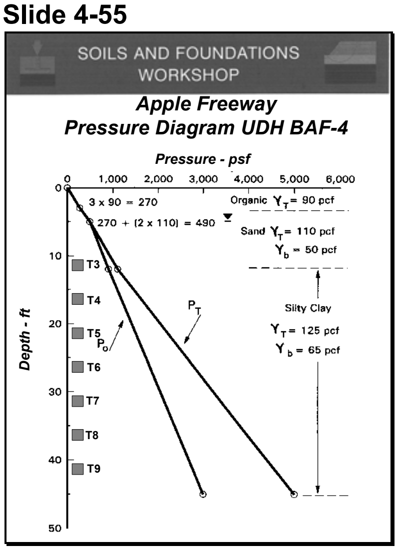
Slide 4-54

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



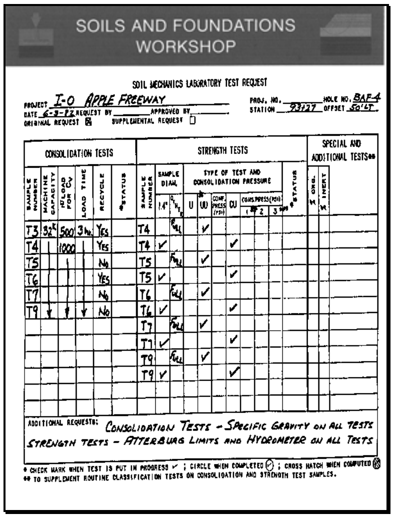
Slide 4-55

Build on the data collection for the Apple Freeway project.



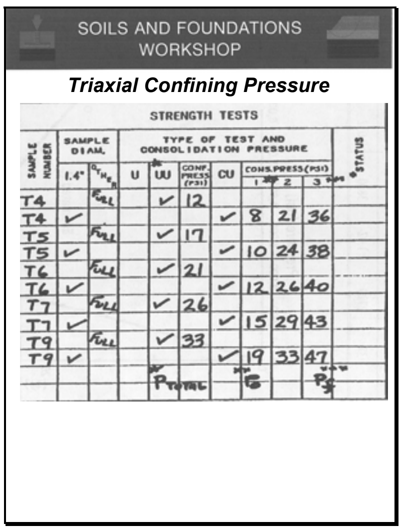
Slide 4-56

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

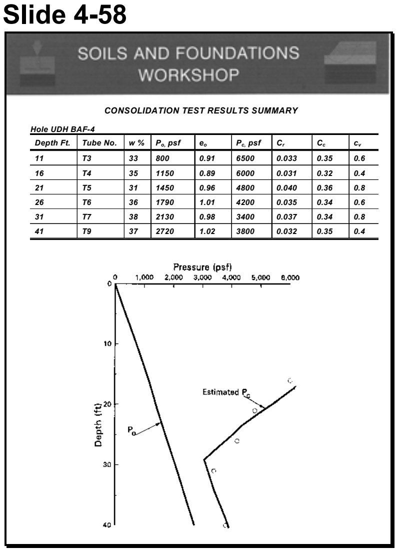
Explain how total pressure is used for UU tests and effective pressure is used for CU tests. Make sure students convert the pressures to psi which is used for gage pressure.



Sample Number	Sample Diam. 1.4"	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}			$\bar{\sigma}$		P_s	

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

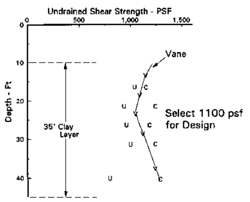
When showing solutions, stress the plotting of the P_c and SS values with depth. Impress on students that all test values should not simply be averaged to find the mean value.

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

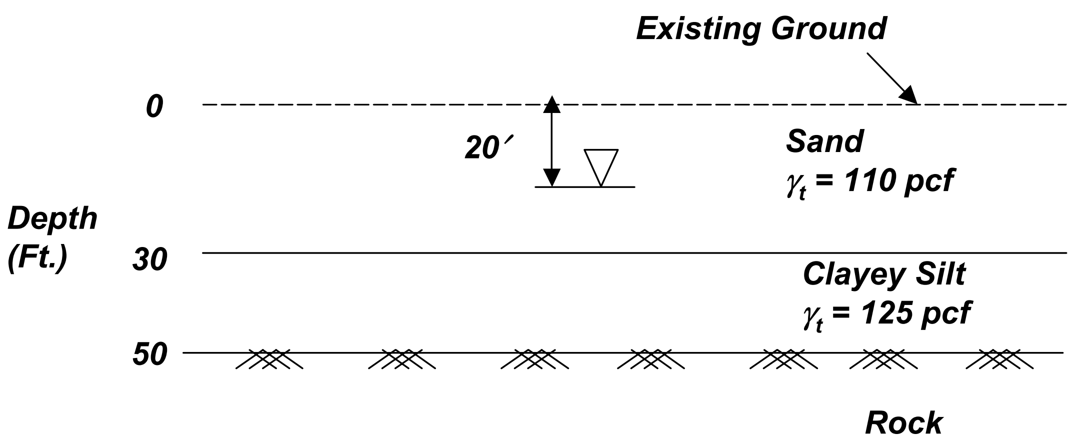
Slide 4-61

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)