NHI Course 132012

Soils and Foundations Workshop

Participant Workbook

April 2002

NHI COURSE 132012
SOILS AND FOUNDATIONS WORKSHOP
PARTICIPANT WORKBOOK

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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.

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.

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LESSON 1

TOPIC 1

Workshop Introduction

SOILS AND FOUNDATIONS WORKSHOP

Soils and Foundations Workshop

National Highway Institute
Course #132012

Slide 1-1-1

SOILS AND FOUNDATIONS WORKSHOP

HOUSEKEEPING

- ***Registration***
- ***Continuing Education Credits***
- ***Breaks***
- ***Restrooms***
- ***Course Evaluation***

Slide 1-1-2

SOILS AND FOUNDATIONS WORKSHOP

WHO ARE WE?

WHO ARE YOU?

Slide 1-1-3

SOILS AND FOUNDATIONS WORKSHOP

SEE ERRATA AT

- ***WWW.FHWA.DOT.GOV/ BRIDGE***

- ***GEOTECHNICAL***
- ***PUBLICATIONS***
- ***SOILS AND FOUNDATIONS***

Slide 1-1-4

SOILS AND FOUNDATIONS WORKSHOP

Workshop Introduction

Lesson 1 - Topic 1

Slide 1-1-5

SOILS AND FOUNDATIONS WORKSHOP

Course Objective

- ***Participants will recognize the minimum acceptable level of geotechnical effort needed for the design and construction of a successful highway project.***

Slide 1-1-6

SOILS AND FOUNDATIONS WORKSHOP

Overall Learning Objective

Participants will recognize the minimum levels of geotechnical knowledge and skill needed for a successful highway project

and

will be able to apply that knowledge to their local agencies and conditions.

Slide 1-1-7

SOILS AND FOUNDATIONS WORKSHOP

Course Content

- ***SITE EXPLORATION***
- ***BASIC SOIL PROPERTIES***
- ***LABORATORY TESTING***
- ***SLOPE STABILITY***
- ***EMBANKMENT SETTLEMENT***
- ***SPREAD FOOTING DESIGN***
- ***PILE DESIGN***
- ***CONSTRUCTION ASPECTS***
- ***FOUNDATION REPORT***

Slide 1-1-8

SOILS AND FOUNDATIONS WORKSHOP

Definition of Learning Outcomes

Knowledge

- ***Ability to Understand a Technical Process***
- ***Learned by Presentation***

Skill

- ***Ability to Perform a Technical Task***
- ***Learned by Practice***

Slide 1-1-9

SOILS AND FOUNDATIONS WORKSHOP

Acquired Knowledge vs. Acquired Skill

Categorize the Following Learning Results as Either Knowledge or Skill?

- ***List Pile Types***
- ***Evaluate Pile Design Alternates***
- ***Calculate Bearing Capacity***
- ***Construct an Effective Stress Diagram***
- ***Recall Exploration Equipment Types***
- ***Describe a Pile Load Test***

Slide 1-1-10

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

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

Slide 1-1-2-3

Geotechnical Participation in Project Phases

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

Slide 1-1-2-4

Geotechnical Participation in Project Phases (Cont'd)

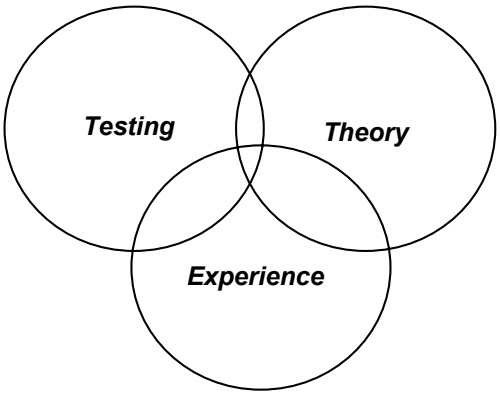
- ***Advance Detailed Plans***
  - ***Complete Testing and Analysis***
  - ***Submit Foundation Investigation Report***
- ***Final Design***
  - ***Review Final Plans***
  - ***Prepare Pre-bid Geotechnical Package***

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



Slide 1-2-7

Terrain Reconnaissance

Slide 1-2-8

Slide 1-2-9

Site Inspection

Slide 1-2-10

Slide 1-2-11

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Slide 1-2-13

Subsurface Borings

Slide 1-2-14

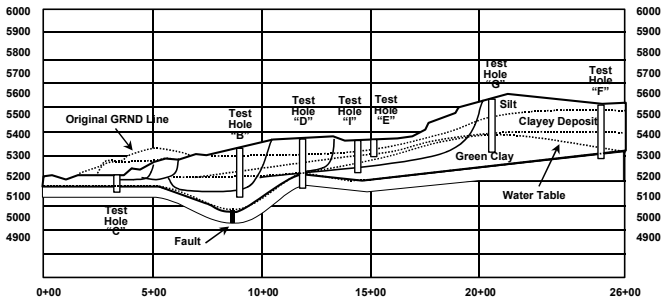
Slide 1-2-15

Slide 1-2-16

Soil Profile

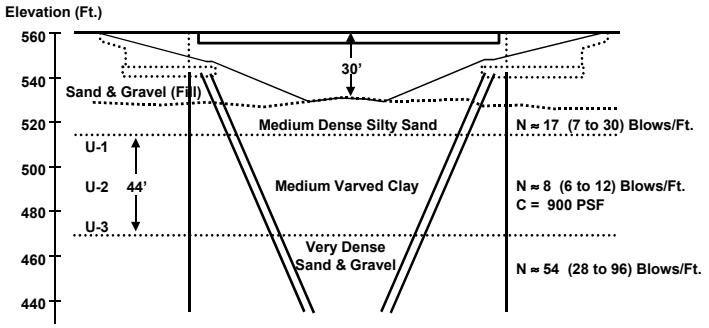
Slide 1-2-17

Pipe Organ Landslide
Preliminary Soil Profile



Slide 1-2-18

Typical Final Soil Profile



Slide 1-2-19

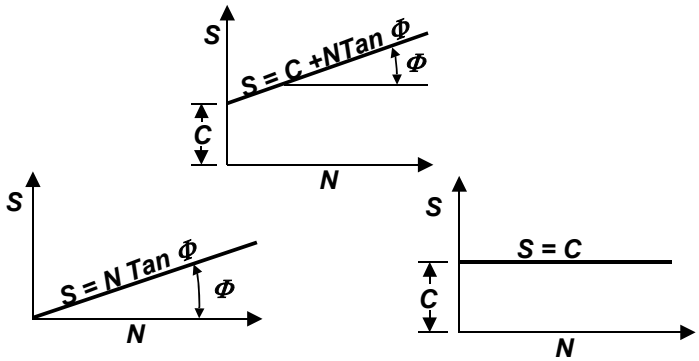
Soil Testing

Slide 1-2-20

Slide 1-2-21

Coulomb's Equation

S= C + (Normal Force) Tan Φ



Slide 1-2-22

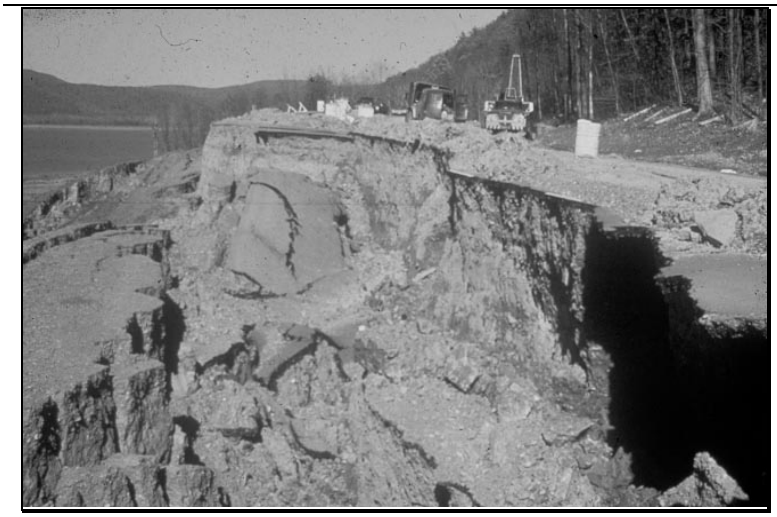
Geotechnical Analysis

Slide 1-2-23

Embankments
Major Design Considerations

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

Slide 1-2-24



Slide 1-2-25

Slide 1-2-26

Slide 1-2-27

Design Solutions to Embankment Problems

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

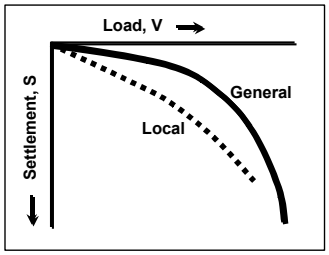
Slide 1-2-28

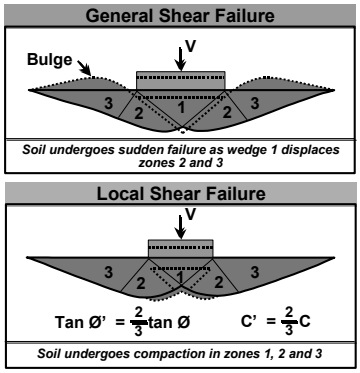
Structural Foundation Topics

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

Slide 1-2-29

Shallow Foundation Failure Mode





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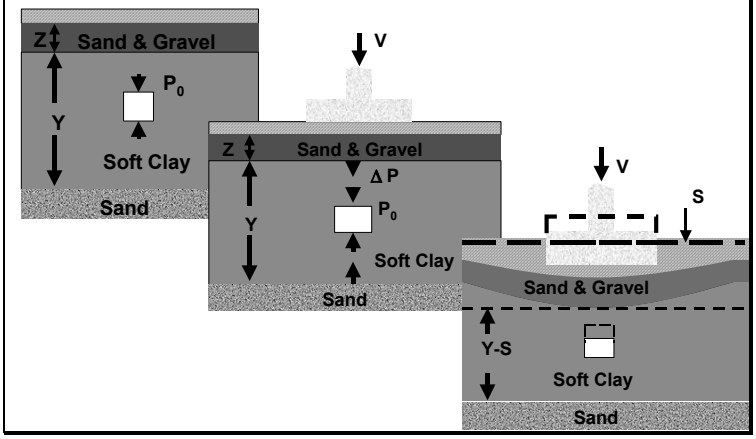
Settlement of Footings on Clay



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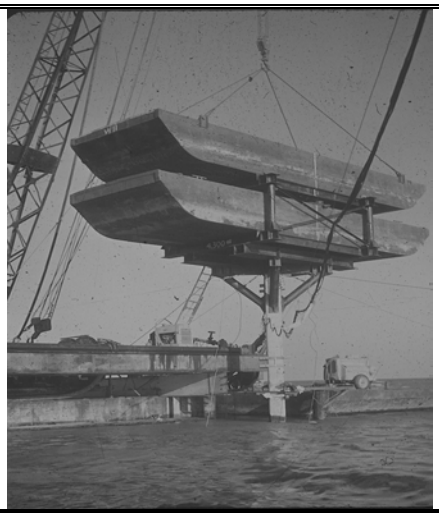
Individual Piles

Method of Estimating Load Capacity

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

Slide 1-2-32



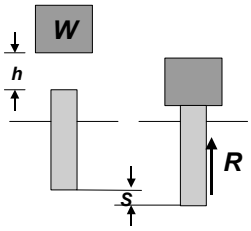
Slide 1-2-33

The Fundamental Pile Driving Formula

Hammer Energy = Work of Soil Resistance

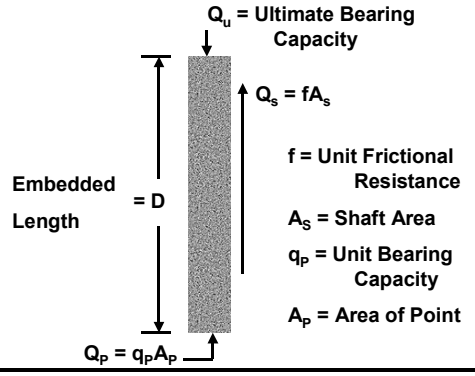
$$W\,h = R\,s$$

$$R = \frac{W\,h}{s}$$



Slide 1-2-34

Ultimate Bearing Capacity - Static Formula Method ($Q_u = Q_p + Q_s$)



Slide 1-2-35

Construction Aspects

- ***Monitoring Construction Operations***
- ***Quality Assurance***

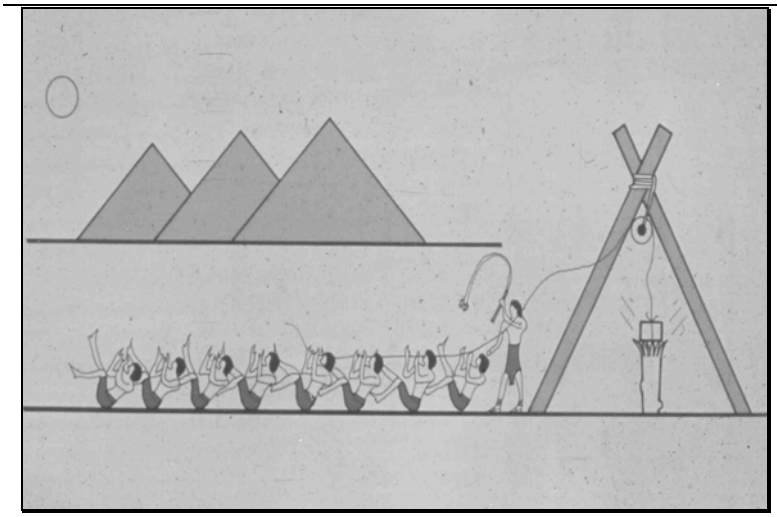
Slide 1-2-36

Select Material Specifications

- ***Specification Item***
  - ***6”-8” Lift Thickness***
  - ***Topsize Restriction***
  - ***Gradation Req’mt***
- ***Reason for Item***
  - ***Small Compaction Equipment***
  - ***Less than 3/4 Lift Thickness***
  - ***Compactibility***

Slide 1-2-37

Slide 1-2-38



Slide 1-2-39

Slide 1-2-40

PROJECT SUCCESS

Cooperation Between
Design & Construction

Slide 1-2-41

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

LESSON 2

TOPIC 1

Site Investigation and Sampling Methods

SOILS AND FOUNDATIONS WORKSHOP

What Site Exploration Techniques are Used by the Highway Agency?

Slide 2-1-1

SITE INVESTIGATION AND SAMPLING METHODS

Lesson 2 - Topic 1

Slide 2-1-2

SITE INVESTIGATION AND SAMPLING METHODS

1. Differentiate Site Exploration and Sampling Methods

2. Describe the SPT Test

ACTIVITY: Question-Answer

Slide 2-1-3

The Six Stages of a Project

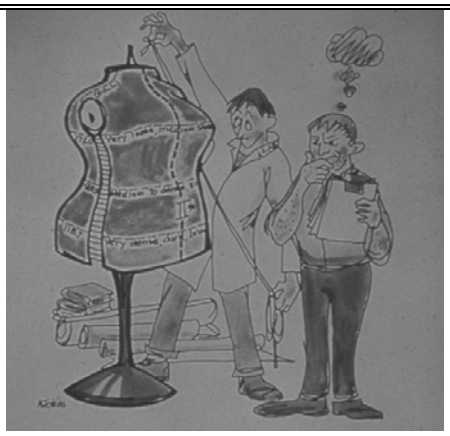
1. Enthusiasm
2. Disillusionment
3. Panic
4. Search for the Guilty
5. Punishment of the Innocent, and
6. Honor and Praise for the Non-Participants

Slide 2-1-4

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



Foundation Engineer

Slide 2-1-6

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

Site Investigation Phases

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

Slide 2-1-8

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

Site Reconnaissance (Cont'd)

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

Slide 2-1-10

Slide 2-1-11

Slide 2-1-12

"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

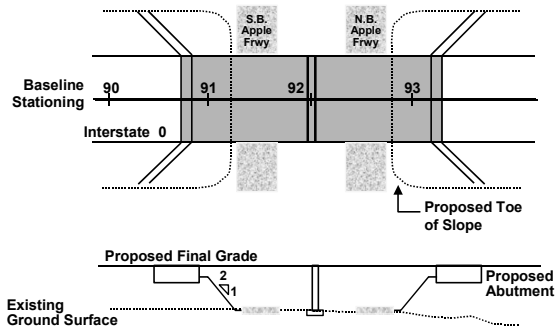
Slide 2-1-13

Detailed Investigation

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

Slide 2-1-14

Preliminary Bridge Layout



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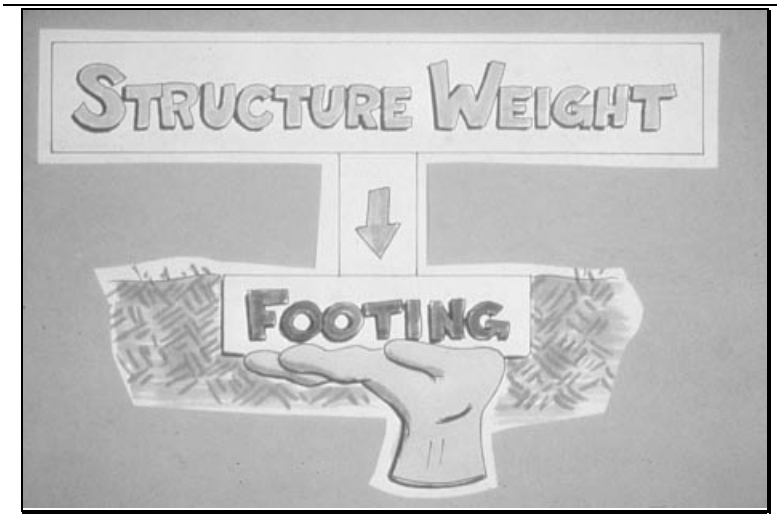

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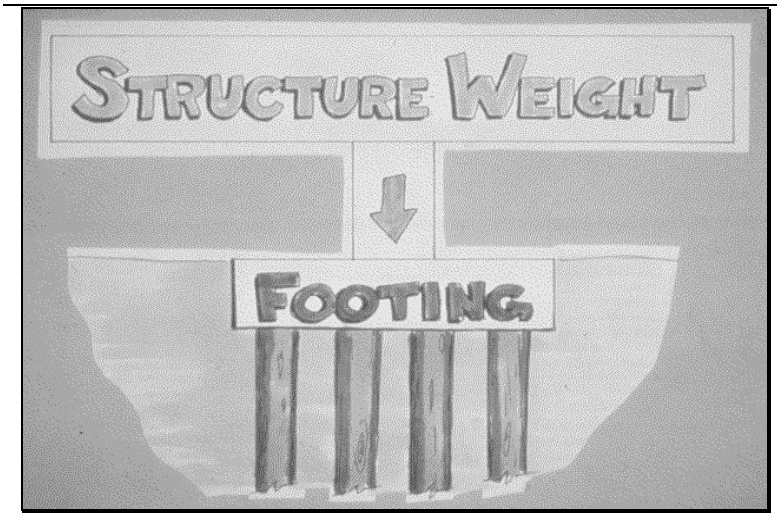


Slide 2-1-17

Detailed Investigation Relevant Information

- ***Soil Strata***
  - ***Depth, Thickness, Variability***
  - ***Visual Description and Lab Classification***
  - ***Relative Engineering Properties***
- ***Ground Water Elevations***

Slide 2-1-18

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

Exploration Methods and Equipment

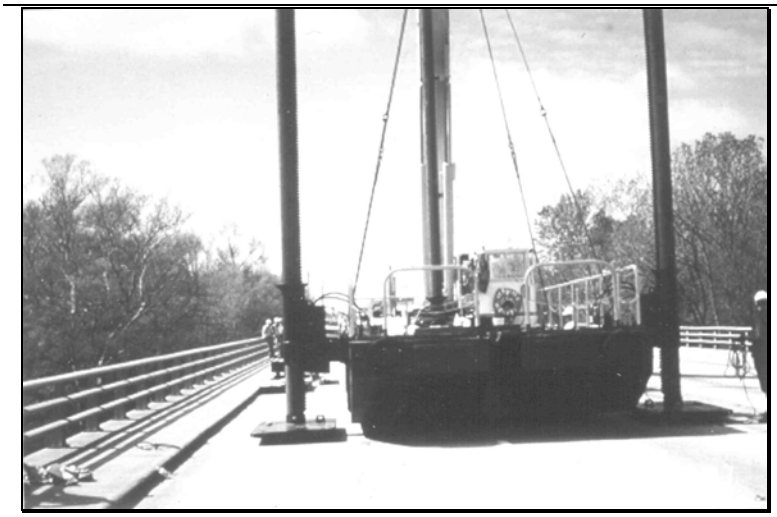
Slide 2-1-20

Slide 2-1-21

Slide 2-1-22

Slide 2-1-23

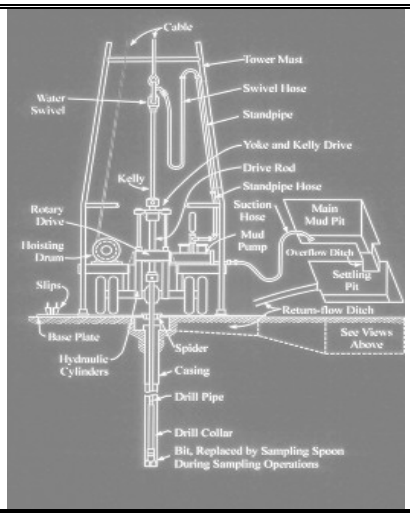
Slide 2-1-24



Slide 2-1-25

Slide 2-1-26

Drill Rig Schematic

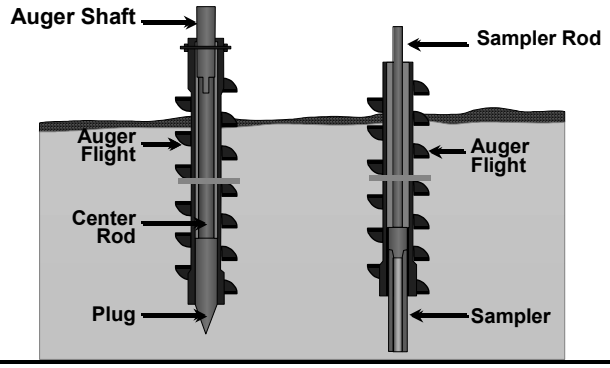


Slide 2-1-27

Slide 2-1-28

Slide 2-1-29

Hollow Stem Auger Plugged for Augering and Used for Sampling



Slide 2-1-30

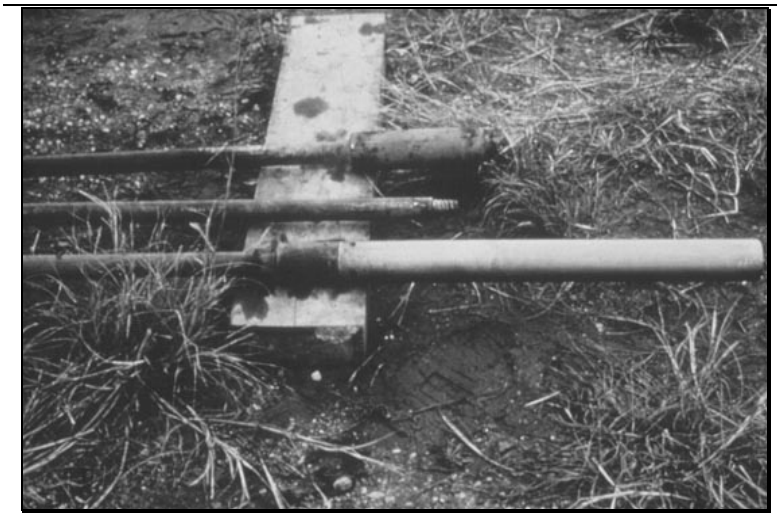
Soil Sampling and Testing Methods

Slide 2-1-31

Cohesive Soils

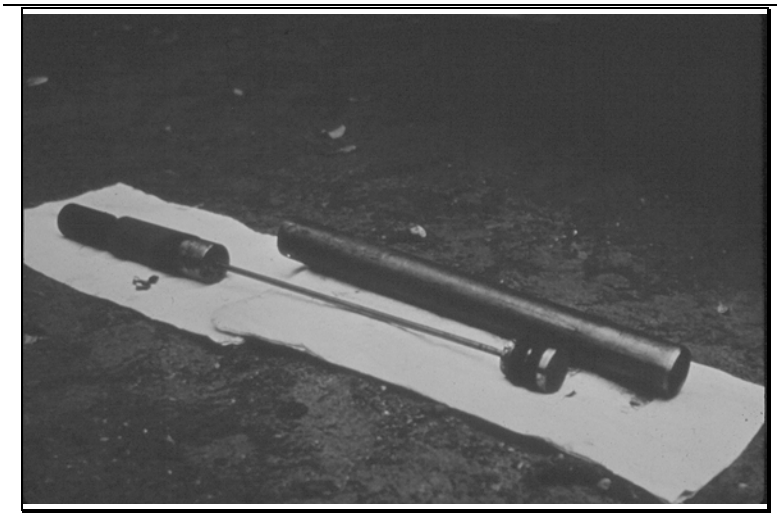
"Undisturbed" Tube Samples
(Shelby or Piston Sampler)

Slide 2-1-32



Slide 2-1-33

Slide 2-1-34

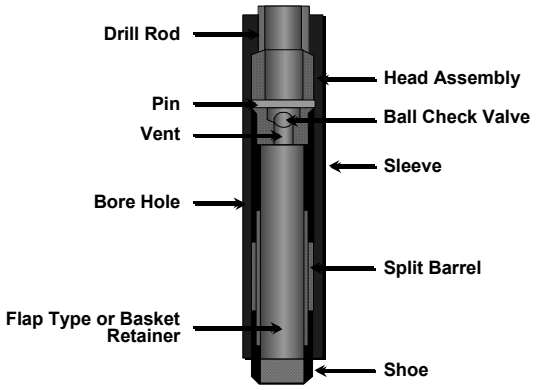


Slide 2-1-35

"Sampling of Granular Soils Use Split Barrel Sampler"

Slide 2-1-36

Split Barrel Sampler



Slide 2-1-37

Slide 2-1-38

Slide 2-1-39

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

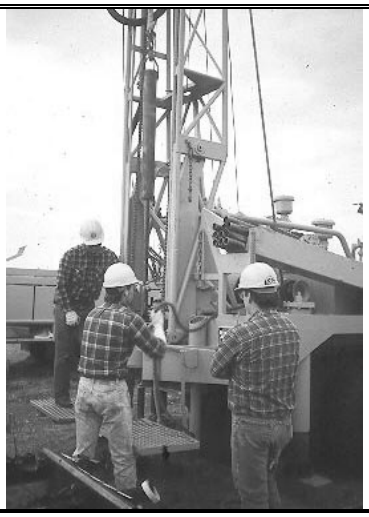
The Standard Penetration Test (SPT)

2" O.D. Sampler

140# Hammer/30" Drop

N = Blows/Foot

Slide 2-1-40



Slide 2-1-41

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

Relative Density of Sand Based on SPT N -Values

Slide 2-1-43

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

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

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

Gravels - What to do?

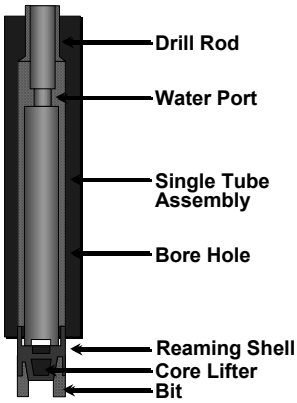
- ***SPT may not be Dependable***
- ***Can Use Oversize Sample Spoon***
- ***Can Use Dynamic Cone for Correlation to SPT Test***

Slide 2-1-47

Rock Sampling

Slide 2-1-48

Single Tube Core Barrel



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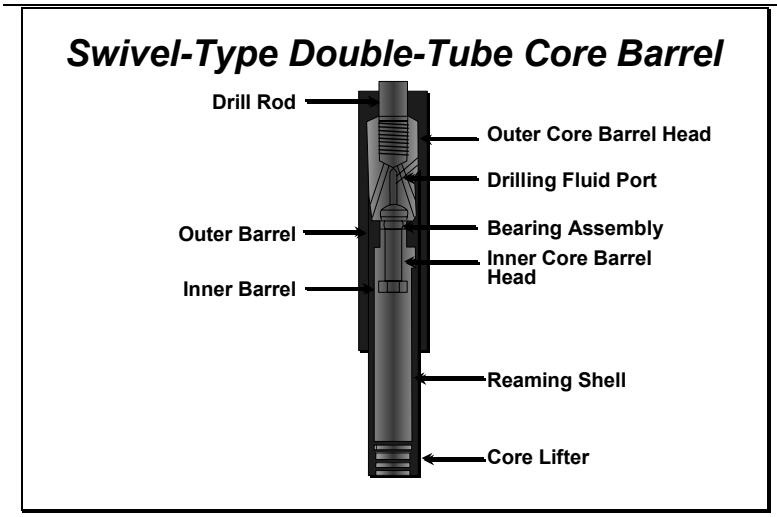
Slide 2-1-50



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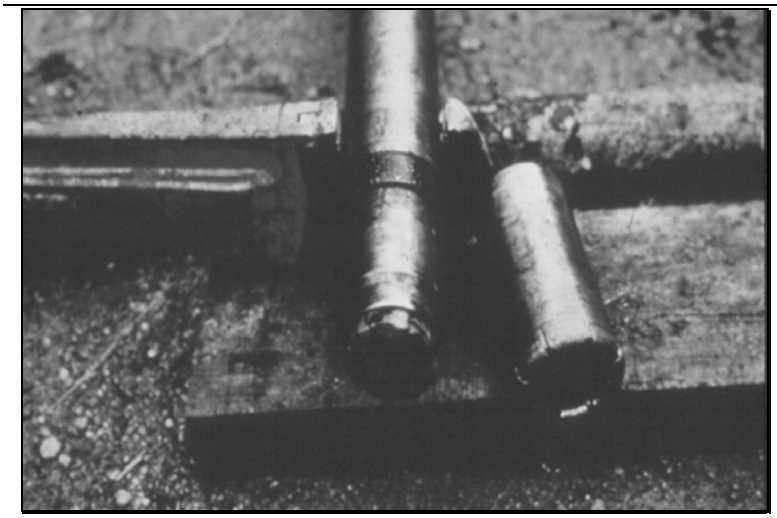
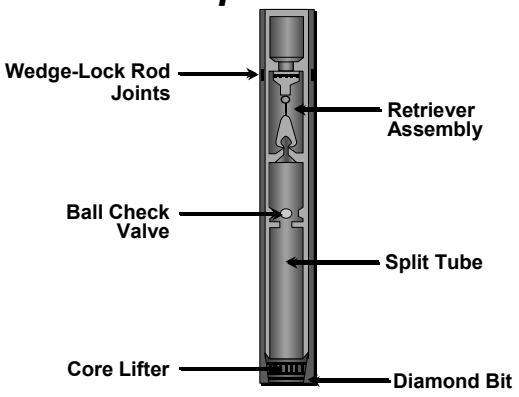


Slide 2-1-52

Wire-Line Sampler



Slide 2-1-53

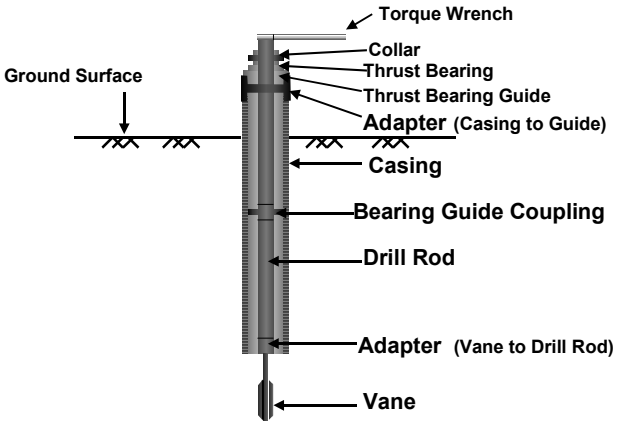
Slide 2-1-54

In-Situ Testing

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

Slide 2-1-55

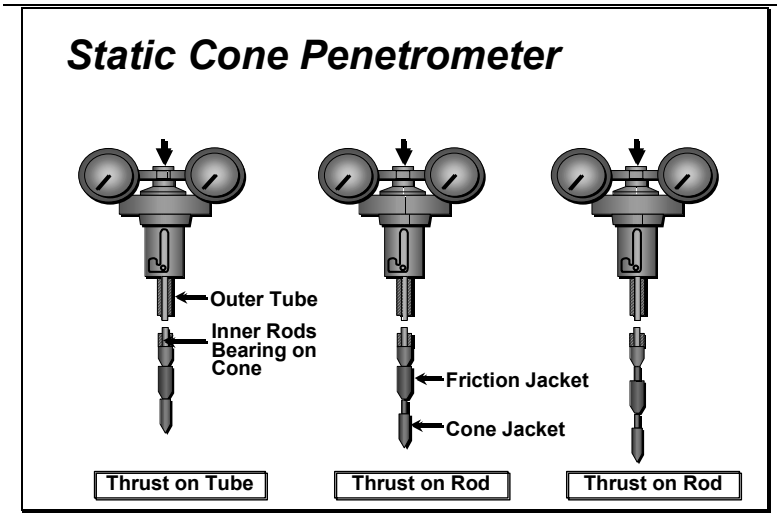
Vane Shear Device



Slide 2-1-56

Slide 2-1-57

Slide 2-1-58



Slide 2-1-59

Slide 2-1-60

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

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

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

SOILS AND FOUNDATIONS WORKSHOP

How Much Exploration? (Cont'd)

This is the Place to Put Your Money, Time and Effort!!!

- *Reduce Failures*
- *Prevent Overconservative Design*
- *Reduce Claims*

More than 50% of Highway Construction Claims are Related to Geotechnical Items.

Slide 2-1-64

SOILS AND FOUNDATIONS WORKSHOP

Highway Embankment and Cuts

- ***Borings Typically Spaced 200' to 400'***
- ***At Least One Boring Per Landform***
- ***Boring Depth = Twice Embankment Height***
- ***Cut Boring Depth at Least 15' Below Depth of Cut***

Slide 2-1-65

SOILS AND FOUNDATIONS WORKSHOP

Approach Embankments

- ***Soft Ground Conditions Require More Detailed Exploration as Stability and Settlement Values Must be Established prior to Structural Foundation Design.***
- ***Borings Must Extend into Competent Soil or Rock (Depth Determined by Structural Design Criteria)***
- ***Shallow Auger Explorations Commonly Made to Determine Depth of Unsuitable Surface Soils and Topsoil.***

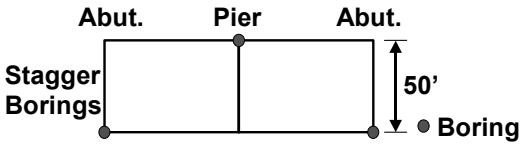
Slide 2-1-66

SOILS AND FOUNDATIONS WORKSHOP

"MINIMUM" Program For Structure Site

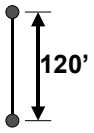
NUMBER OF BORINGS

- ***ONE boring at EACH pier and abutment under 100' long***



- ***TWO borings at EACH pier and abutment over 100' long, one at each end***

Abutment borings also used for Approach Embankment Design



Slide 2-1-67

SOILS AND FOUNDATIONS WORKSHOP

"MINIMUM" Program For Structure Site (Cont'd)

DEPTH OF BORINGS

- ***Est. From Site Recon or Existing Data or "Rule of Thumb".***
- ***Extend Boring Depth into Competent Soil using Criteria such as:***

SPT - N ≥ 20 for 20 Consecutive ft. of Drilling & Sampling

OR

Core Min. 10 ft. into Rock with Avg. Recovery ≥ 50%

Slide 2-1-68

SOILS AND FOUNDATIONS WORKSHOP

"MINIMUM" Program For Structure Site (Cont'd)

SAMPLING FREQUENCY

- ***Continuous SPT top 15' of borings where spread footings may be placed on natural soil.***
- ***SPT at 5' interval elsewhere.***

Slide 2-1-69

SOILS AND FOUNDATIONS WORKSHOP

"MINIMUM" Program For Structure Site (Cont'd)

- ***"Undisturbed" Shelby tube sample every 5' in at least one boring in cohesive soil (increase to 10' intervals after 30')***
- ***Soft clay - In - situ vane shear tests at 5' to 10' intervals***
- ***Make SPT borings first, then pick location of boring(s) for undisturbed samples based on preliminary evaluation of SPT borings.***

Slide 2-1-70

SOILS AND FOUNDATIONS WORKSHOP

"MINIMUM" Program For Structure Site (Cont'd)

WATER LEVEL

- ***Encountered during drilling***
- ***Completion of boring***
- ***24 hour min. after hole completed***
- ***Leave plastic perforated pipe in hole if want long term readings (allow minimum 1 week for W.L. to stabilize in clay)***

Slide 2-1-71

SOILS AND FOUNDATIONS WORKSHOP

"MINIMUM" Program For Structure Site (Cont'd)

DRILLERS DUTIES

- ***"Rough" visual description of samples***
- ***Prepare field drill log***
- ***SPT samples in jars or bags***
- ***Shelby tube samples (protect) to lab***

BORING NUMBERS

- ***Use unique numbering system Example : DH-BAF-1***

Slide 2-1-72

SOILS AND FOUNDATIONS WORKSHOP

"Extent" of Work Established as Work Progresses in Field

Driller Notify Foundation Engr. When Last Boring Begun

Need Good Communication & Coordination!!!

Slide 2-1-73

SOILS AND FOUNDATIONS WORKSHOP

SITE INVESTIGATION AND SAMPLING METHODS

1. ***Differentiate Site Exploration and Sampling Methods***
2. ***Describe the SPT Test***

ACTIVITY:

Question-Answer

Slide 2-1-74

SOILS AND FOUNDATIONS WORKSHOP

What Site Exploration Techniques are Used by the Highway Agency?

Slide 2-1-75

LESSON 2

TOPIC 2

Layout of Subsurface Investigation for Bridge Foundation

SOILS AND FOUNDATIONS WORKSHOP

LAYOUT OF SUBSURFACE INVESTIGATION FOR BRIDGE FOUNDATION

Lesson 2 - Topic 2

Slide 2-2-1

SOILS AND FOUNDATIONS WORKSHOP

Layout of Subsurface Investigation Program

- ***Plan Location***
- ***Type***
- ***Depth and Sampling Frequency for Exploration***

Slide 2-2-2

SOILS AND FOUNDATIONS WORKSHOP

Explain the Steps in the Layout of a Subsurface Exploration Program for a Typical Bridge Project

Slide 2-2-3

SOILS AND FOUNDATIONS WORKSHOP

Site Exploration

Terrain Reconnaissance

Site Inspection

Subsurface Borings

Basic Soil Properties

Laboratory Testing

Slope Stability

Embankment Settlement

Spread Footing Design

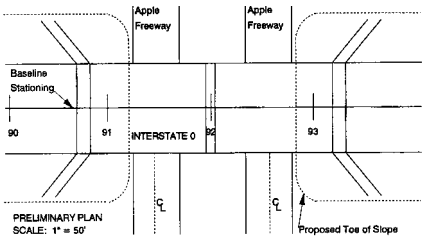
Pile Design

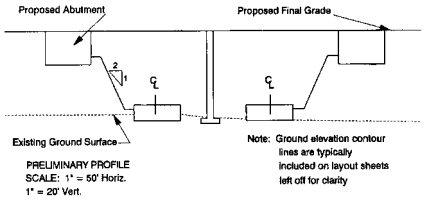
Construction Aspects

Slide 2-2-4

SOILS AND FOUNDATIONS WORKSHOP

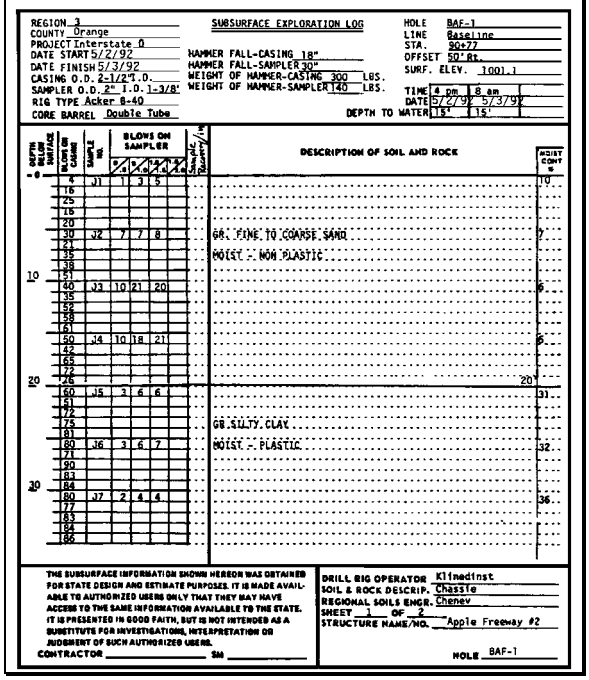
Given: Field inspection showed wet area with cattails in vicinity of East abutment. Soil map showed structure to be located in a delta landform.





Slide 2-2-5

SOILS AND FOUNDATIONS WORKSHOP



REGION 3
COUNTY Orange
PROJECT Interstate 0
DATE START 5/2/92
DATE FINISH 5/3/92
CASING O.D. 2-1/2" I.D.
SAMPLER O.D. 2" I.D. 1-3/8"
RIG TYPE Acker B-40
CORE BARREL Double Tube

SUBSURFACE EXPLORATION LOG

HAMMER FALL-CASING 18"
HAMMER FALL-SAMPLER 30"
WEIGHT OF HAMMER-CASING 300 LBS.
WEIGHT OF HAMMER-SAMPLER 140 LBS.

HOLE BAF-1
LINE Baseline
STA. 90+77
OFFSET 50' Rt.
SURF. ELEV. 1001.1
TIME 4 pm 8 am
DATE 5/2/92 5/3/92
DEPTH TO WATER 15' 15'

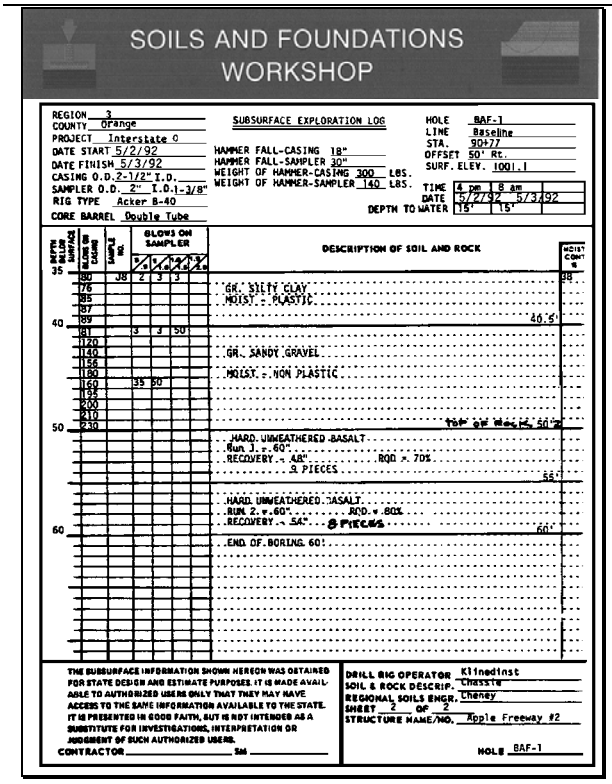
DEPTH BELOW SURFACE	BLOWS ON CASING	SAMPLE NO.	BLOWS ON SAMPLER 0/6	6/12	12/18	18/24	Sample/Core Recovery	DESCRIPTION OF SOIL AND ROCK	MOIST CONT %
0	4	J1	1	3	5				10
	16								
	25								
	15								
	20								
	30	J2	7	7	8			GR. FINE TO COARSE SAND	7
	21								
	35							MOIST - NON PLASTIC	
	38								
10	51								
	40	J3	10	21	20				6
	35								
	52								
	58								
	61								
	50	J4	10	18	21				6
	42								
	65								
	72								
20	26								20
	60	J5	3	6	6				31
	61								
	72								
	75							GR SILTY CLAY	
	81								
	80	J6	3	6	7			MOIST - PLASTIC	32
	71								
	90								
	83								
30	84								
	80	J7	2	4	4				36
	77								
	83								
	84								
	86								

THE SUBSURFACE INFORMATION SHOWN HEREON WAS OBTAINED FOR STATE DESIGN AND ESTIMATE PURPOSES. IT IS MADE AVAILABLE TO AUTHORIZED USERS ONLY THAT THEY MAY HAVE ACCESS TO THE SAME INFORMATION AVAILABLE TO THE STATE. IT IS PRESENTED IN GOOD FAITH, BUT IS NOT INTENDED AS A SUBSTITUTE FOR INVESTIGATIONS, INTERPRETATION OR JUDGMENT OF SUCH AUTHORIZED USERS.

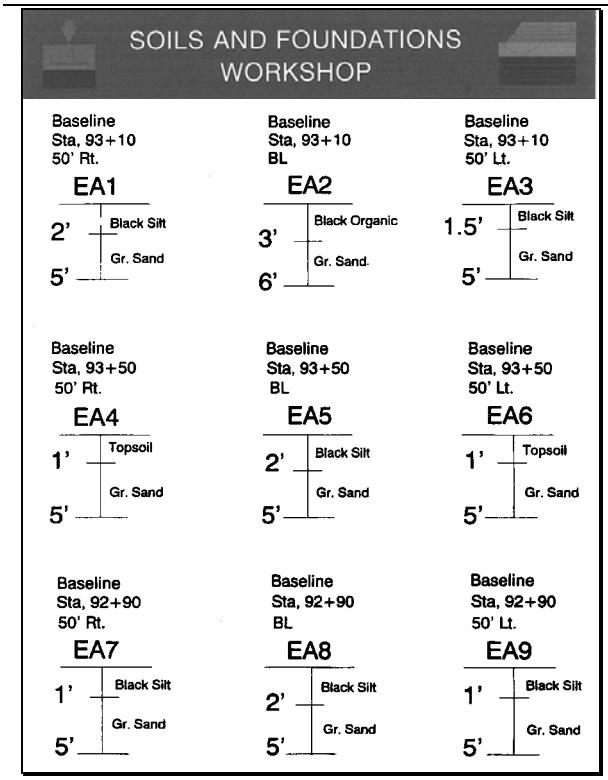
CONTRACTOR _____ SM _____

DRILL RIG OPERATOR Klinedinst
SOIL & ROCK DESCRIP. Chassie
REGIONAL SOILS ENGR. Cheney
SHEET 1 OF 2
STRUCTURE NAME/NO. Apple Freeway #2
HOLE BAF-1

Slide 2-2-6

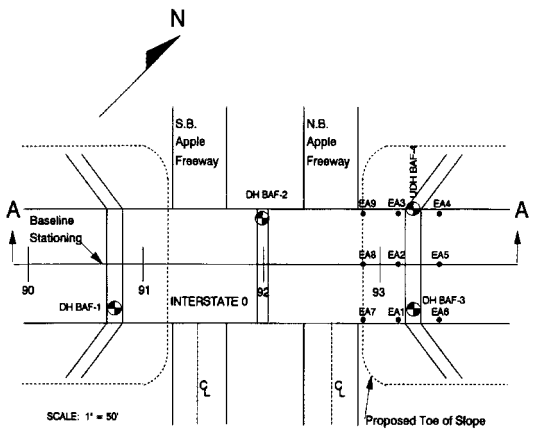


Slide 2-2-7



Slide 2-2-8

SOILS AND FOUNDATIONS WORKSHOP



Slide 2-2-9

SOILS AND FOUNDATIONS WORKSHOP

Site Exploration

- ***Terrain Reconnaissance***
  - ***Delta Landform - Possible Clay Deposit Buried***
- ***Site Inspection***
  - ***Unsuitable Soils Near East Approach Embankment***
- ***Subsurface Borings***
  - ***Auger Hole Define Limits and Depth of Unsuitable Organic Deposit***
  - ***SPT Drill Holes Show Sand Over Clay Over Gravel and Rock***
  - ***Undisturbed Samples and Vane Shear Tests Taken in Clay***

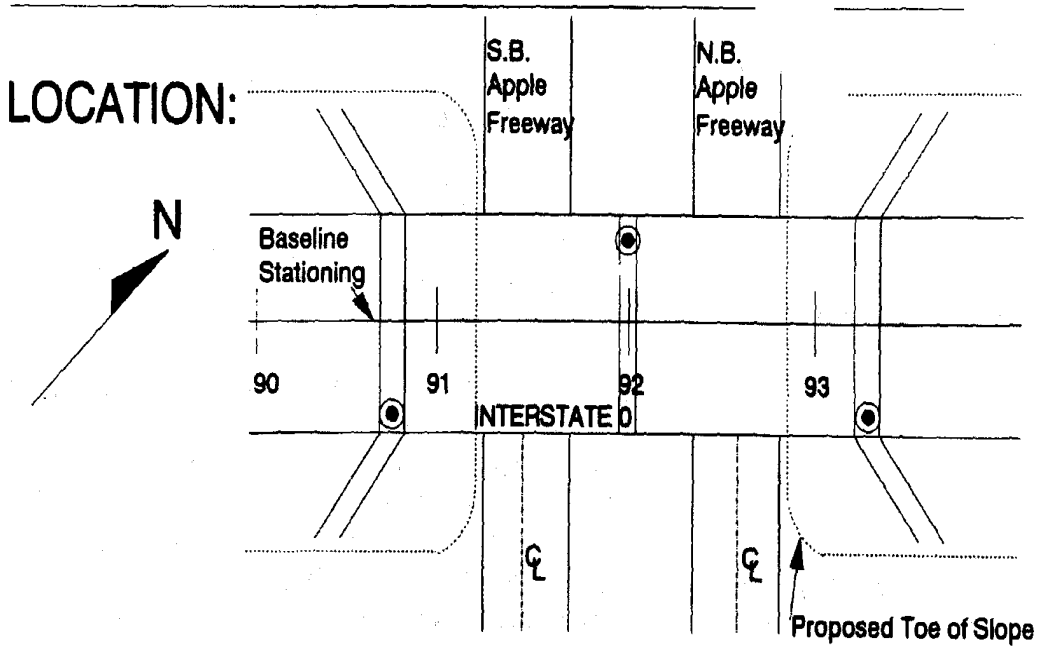
Slide 2-2-10

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.

PLAN SUBSURFACE EXPLORATION PROGRAM



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

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

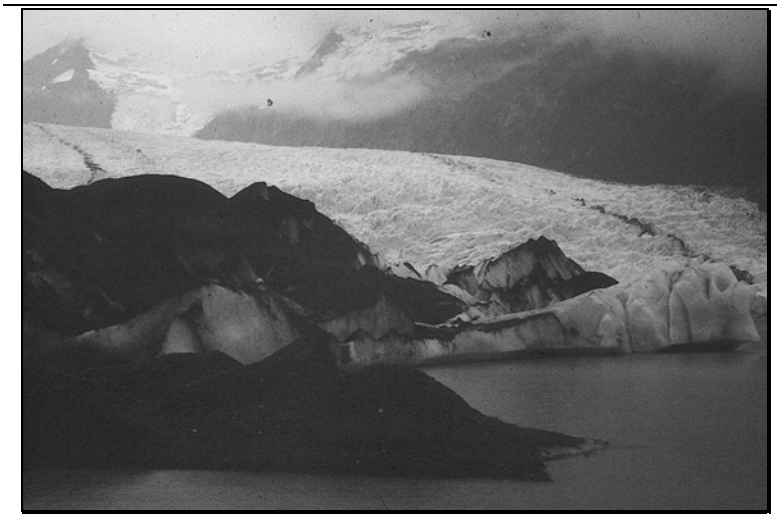
Slide 3-2

Definition of Soil

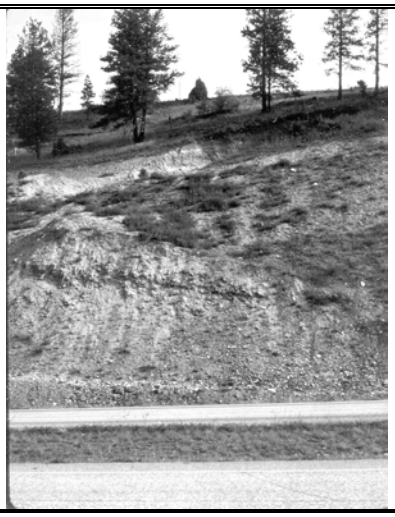
Naturally occurring mineral particles which are fairly readily separated into relatively small pieces and in which the mass may contain air, water, or organic materials.

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



Slide 3-4



Slide 3-5

Slide 3-6

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

Granular Soils

Sands and Gravels

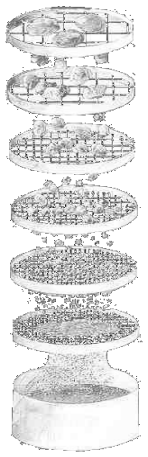
Slide 3-8

Slide 3-9

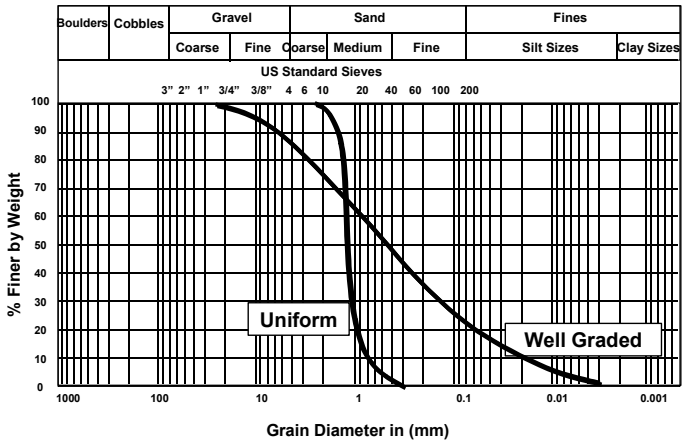
Identify by Grain Size

Slide 3-10

Gradation Test



Slide 3-11



Slide 3-12

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

Fine-Grained Soils

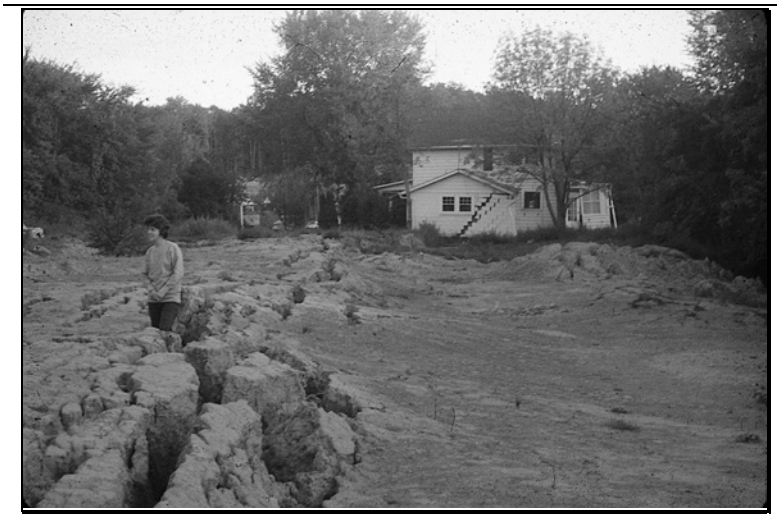
Soil Mineral Types Control Behavior of Silts and Clays More Than Grain Size

Slide 3-14

Cohesive Soils (Clays)

Strength Largely Derived From Cohesion

Slide 3-15

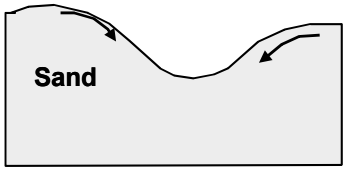


Slide 3-16

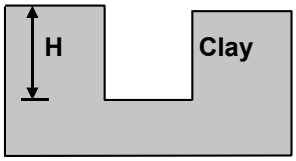
Cohesion

Excavations In Dry Sand Slopes WON'T Stand

Excavations In Stiff Clay Slopes WILL Stand if H<HC



No Cohesion



Cohesion

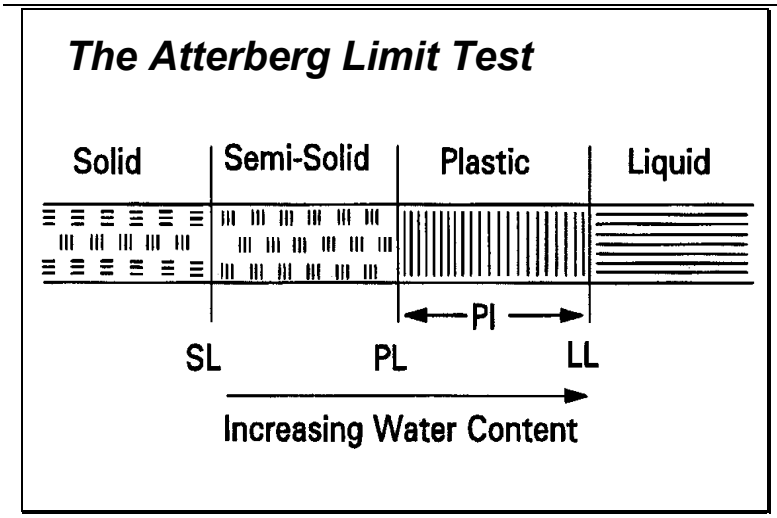
Slide 3-17

Cohesive Soils (Clays)

Identify by Plasticity

Slide 3-18

Slide 3-19



Slide 3-20

Engineering Properties of Cohesive Soils

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

Slide 3-21

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

Silts

Similar to Clays but Exhibit No Cohesion

Slide 3-23

Slide 3-24

Differences Between Silts and Clays

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

Slide 3-25

Engineering Properties of Silts

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

Slide 3-26

Engineering Properties of Silts Compared to Clays

Silts Characteristically Have:

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

Slide 3-27

Organic Soils

Peat, Muck, Organic Silts and Clays Contain Decayed Animal and/or Vegetative Matter (Organic Matter).

Slide 3-28

Organic Soils

Organic Matter is Objectionable Because:

- ***Reduces Load Carrying Capacity***
- ***Increases Compressibility***
- ***Releases Toxic Gases During Excavations***

Slide 3-29

Engineering Properties of Organic Soils

- ***Low Shear Strength***
- ***High Compressibility***
- ***Spongy Structure Which Deteriorates Rapidly***
- ***Acidity and Other Injurious Characteristics to Construction Materials***

Slide 3-30

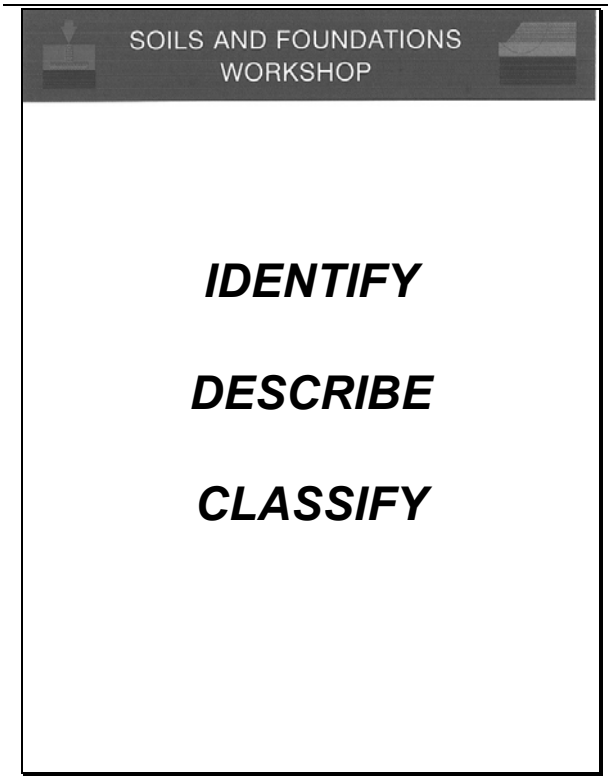
Slide 3-31

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

Slide 3-33



Slide 3-34

SOILS AND FOUNDATIONS WORKSHOP

List the Typical Soil Tests that are Performed in Your Laboratory for a Highway Project

Slide 3-35

SOILS AND FOUNDATIONS WORKSHOP

Lab. Exercise Begins

Slide 3-36

SOILS AND FOUNDATIONS WORKSHOP

Return to Main Classroom

Slide 3-37

SOILS AND FOUNDATIONS WORKSHOP

Geo-Fun: What Soil Types (Silt, Sand, Clay, Gravel, Etc.) Are Used For...

- ***Gardening***
- ***Unpaved Roads***
- ***Water Filter***
- ***Pottery***
- ***Ice Cream***
- ***Kaopectate***
- ***Kitty Litter***

Slide 3-38

SOILS AND FOUNDATIONS WORKSHOP

Site Exploration

Basic Soil Properties

- ***Visual Description***
- ***Classification Tests***
- ***Soil Profile***

Laboratory Testing

Slope Stability

Embankment Settlement

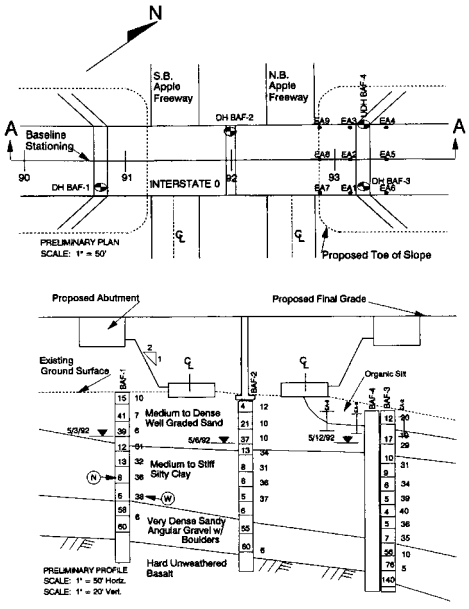
Spread Footing Design

Pile Design

Construction Aspects

Slide 3-39

SOILS AND FOUNDATIONS WORKSHOP



Slide 3-40

SOILS AND FOUNDATIONS WORKSHOP

Basic Soil Properties

- ***Visual Description***
  - ***Predominate Soil Types are Sand, Silty Clay and Sandy Gravel***
- ***Classification Tests***
  - ***Moisture Content and Unit Weight Determined***
- ***Soil Profile***
  - ***Subsurface Variation of Soil Layers and Ground Water Estimated***

Slide 3-41

SOILS AND FOUNDATIONS WORKSHOP

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 3-42

LESSON 4

Laboratory Testing for Foundation Design

LABORATORY TESTING FOR FOUNDATION DESIGN

Lesson 4

Slide 4-1

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

Samples for Lab Tests

Disturbed Samples May Be Used for:

- ***Visual Classification/Description***
- ***Moisture Content***
- ***Specific Gravity***
- ***Atterberg Limits***
- ***Gradation***
- ***Compaction***

Slide 4-3

Samples For Lab Tests (Cont'd)

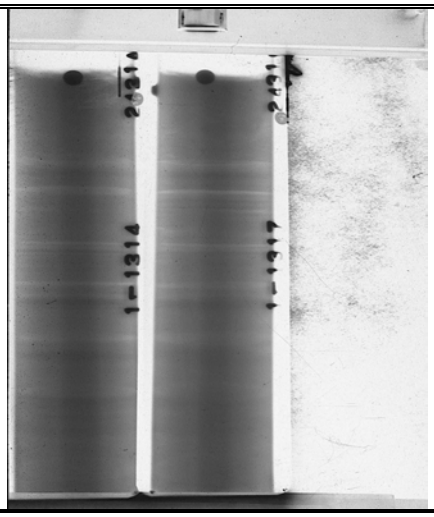
Undisturbed Samples Required For:

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

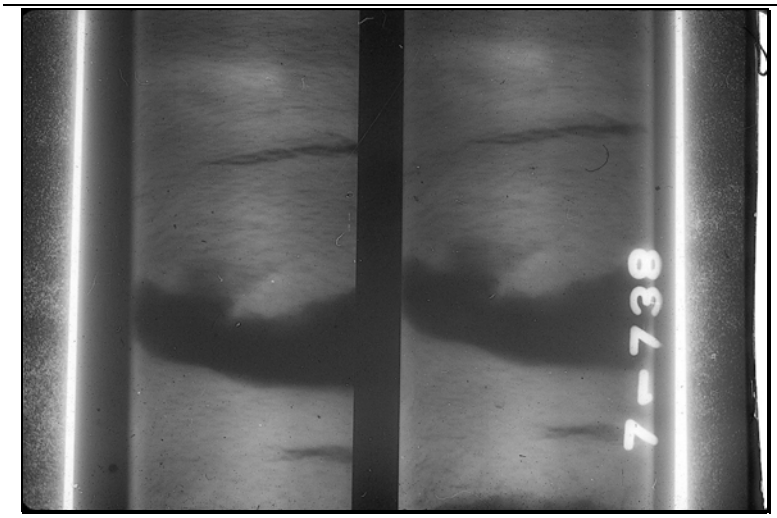
Slide 4-4

Slide 4-5

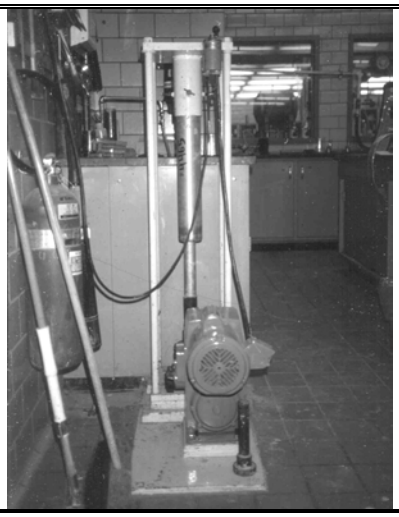
Slide 4-6



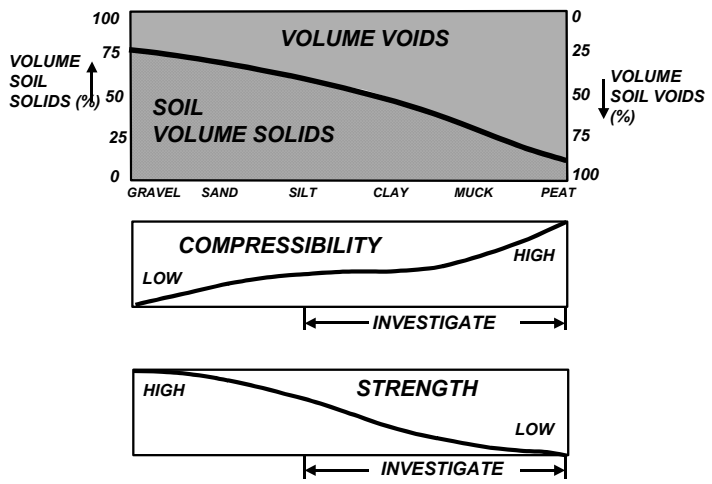
Slide 4-7



Slide 4-8



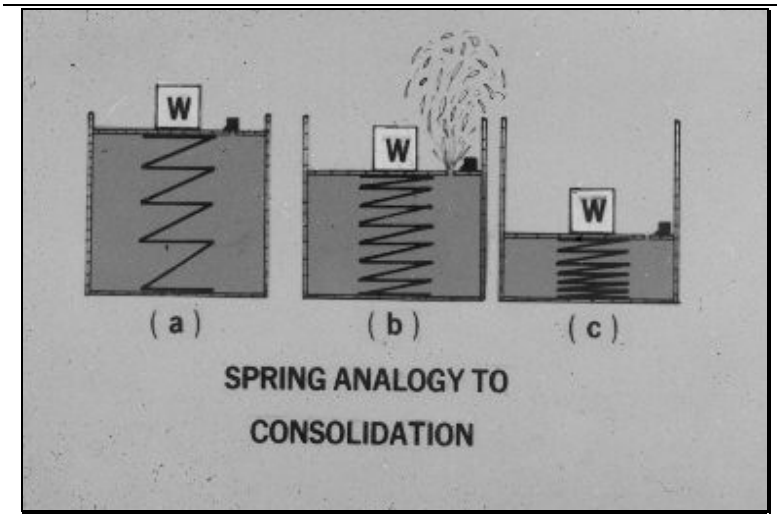
Slide 4-9



Slide 4-10

Total, Effective and Water Stresses

Slide 4-11



Slide 4-12

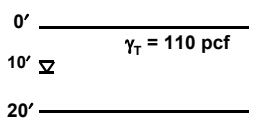
SOILS AND FOUNDATIONS WORKSHOP

How is the Pressure in the Ground Affected by the Location of the Water Table?

Slide 4-13

SOILS AND FOUNDATIONS WORKSHOP

Find P_0 at 20 feet below ground in a sand deposit with a total unit weight of 110 pcf and the water table 10 feet below ground. Plot P_T and P_0 verses depth from 0' – 20'.



Solution: $P_0 = P_T - \mu$

P_T @ 10' = P_0 @ 10' = 10' ×110 pcf = 1100 psf

P_T @ 20' = P_T @ 10' + (10' ×110 pcf) = 2200 psf

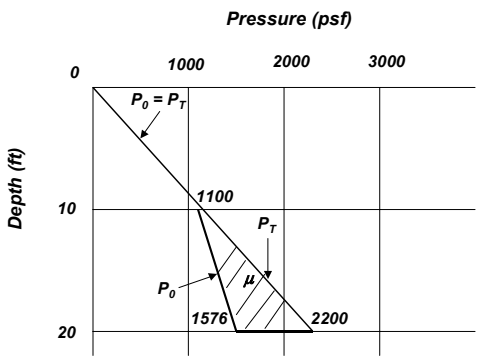
μ @ 20' = 10' ×624 pcf = 624 psf

P_0 @ 20' = P_T @ 20' - μ @ 20' = 2200 – 624 = 1576 psf

Slide 4-14

SOILS AND FOUNDATIONS WORKSHOP

Example 4.1 Solution (Cont'd)

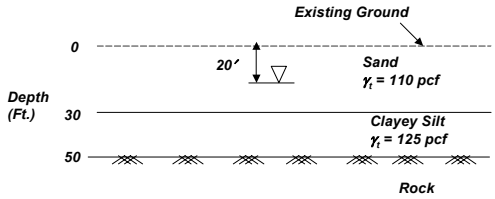


Slide 4-15

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:

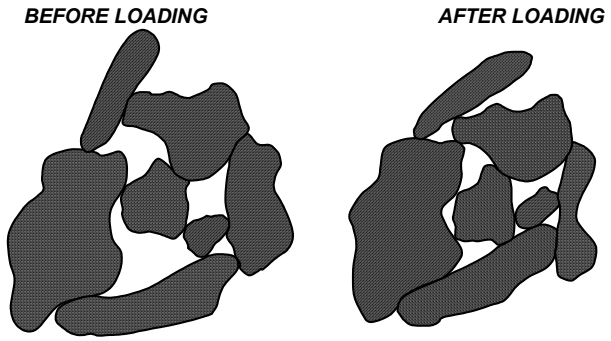
Slide 4-16

Consolidation

Slide 4-17

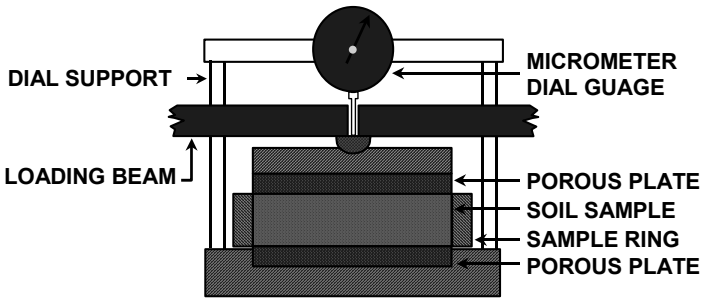
Slide 4-17

PARTICLE READJUSTMENT

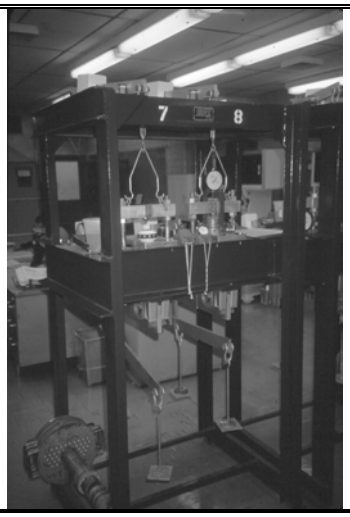


Slide 4-18

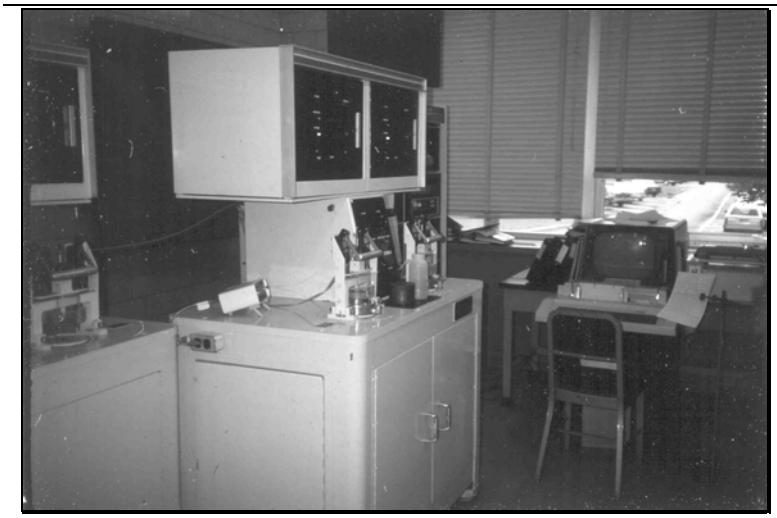
1-D Consolidometer



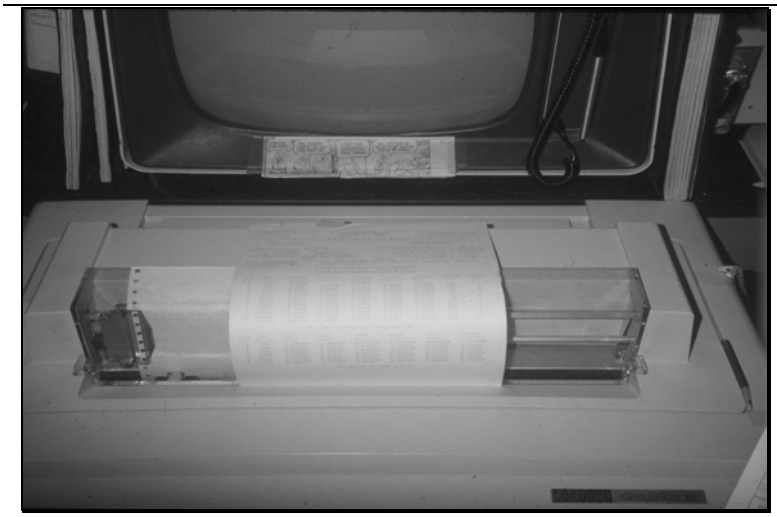
Slide 4-19



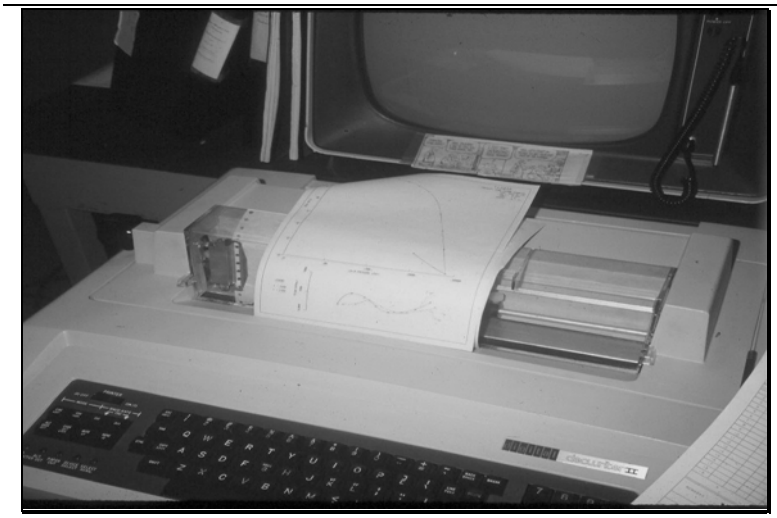
Slide 4-20



Slide 4-21

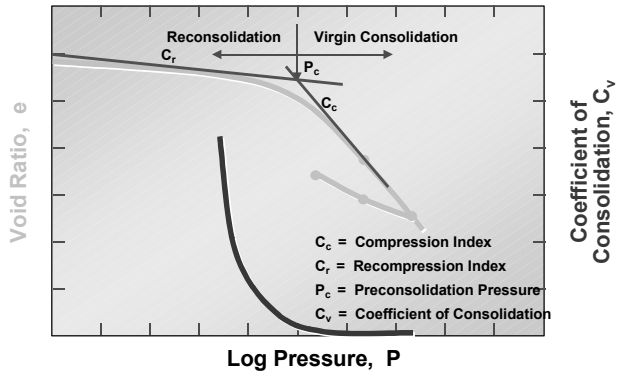


Slide 4-22



Slide 4-23

Void Ratio vs. Log Pressure



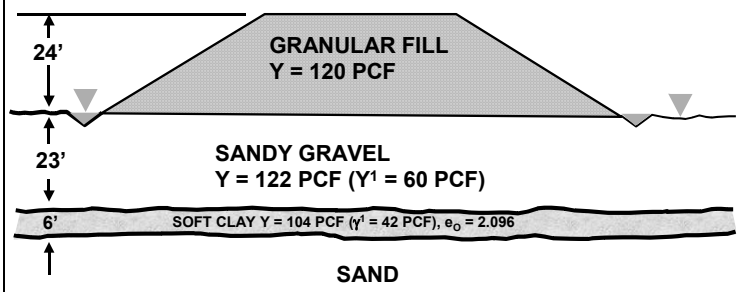
Slide 4-24

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 4-25

Settlement Problem



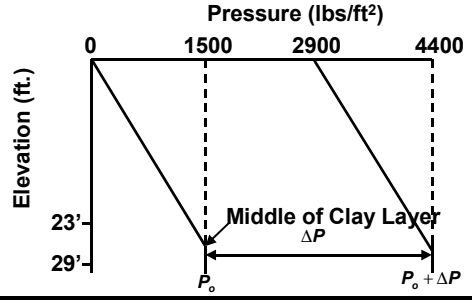
COMPUTE: 1. SETTLEMENT
2. TIME

Slide 4-26

Compute P_o and ΔP at the Center of the Clay Layer

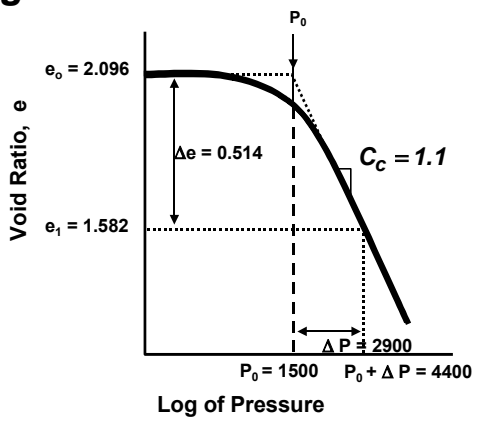
$$P_O = (23')(60) + (3')(42) = 1500\ lbs/ft^2$$

$$\Delta P = (24')(120) = 2900\ lbs/ft^2$$



Slide 4-27

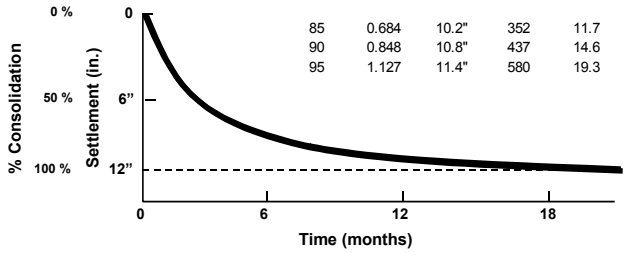
e-log P Curve



Slide 4-28

Time Settlement Curve

U%	T	Settlement	Time From t = 515T 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



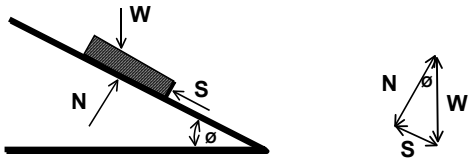
Slide 4-29

Shear Strength

Slide 4-30

Slide 4-31

Frictional Strength



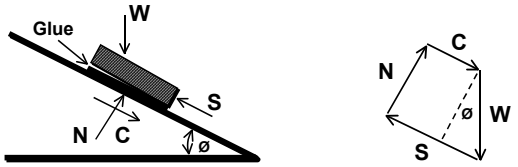
$$\text{Tan } Ø = \frac{S}{N} = \text{Friction}$$

$$\therefore S = N \text{ Tan } Ø$$

S = Shear Force Required to Cause Slip

Slide 4-32

Friction + Cohesion



$$S = C + N \text{ Tan } Ø$$

For Soil: Ø = Angle of Internal Friction
C = Cohesion

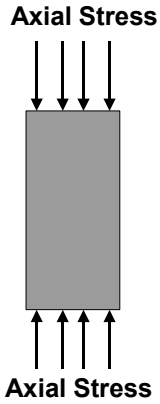
Slide 4-33

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 4-34

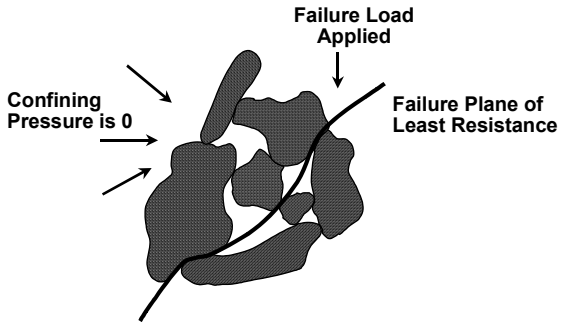
Unconfined Compression Test



Slide 4-35

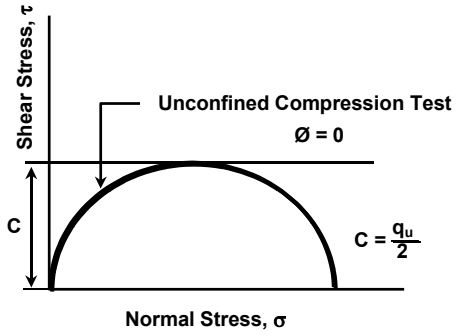
Slide 4-36

Unconfined (U)



Slide 4-37

Unconfined Compression Test



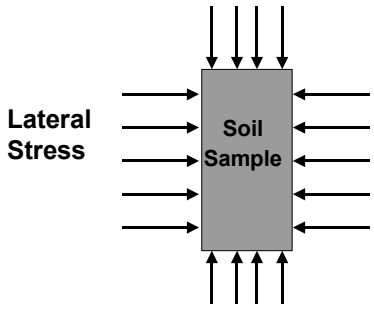
Slide 4-38

Unconfined Compression Test

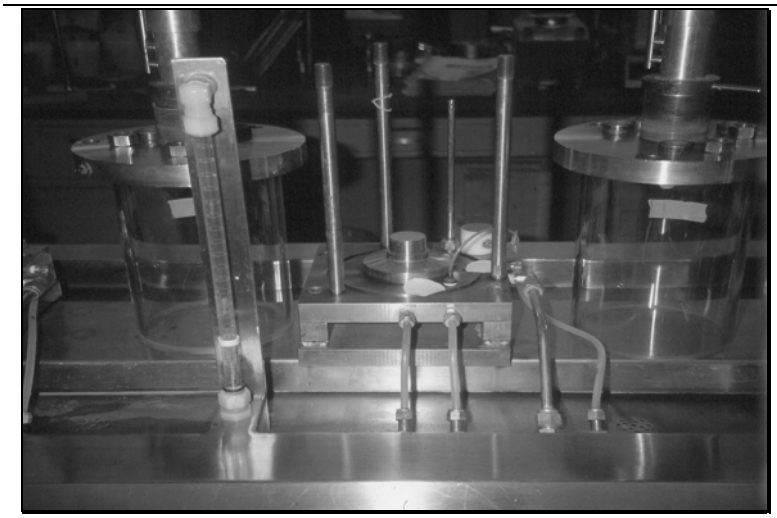
- ***Quick, Economical Test to Approximate the the Shear Strength of Cohesive Soils at Shallow Depths***
- ***Poor Reliability for Samples Extracted From Increasing Depths***
- ***Should Only be Performed on Samples Extruded Directly from the Tube and Tested at Full Diameter***

Slide 4-39

Triaxial Compression



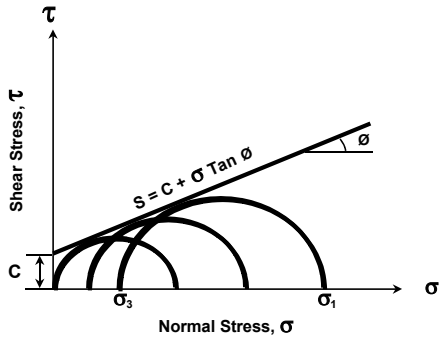
Slide 4-40



Slide 4-41

Slide 4-42

Triaxial Shear Test Results



Slide 4-43

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 4-44

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***

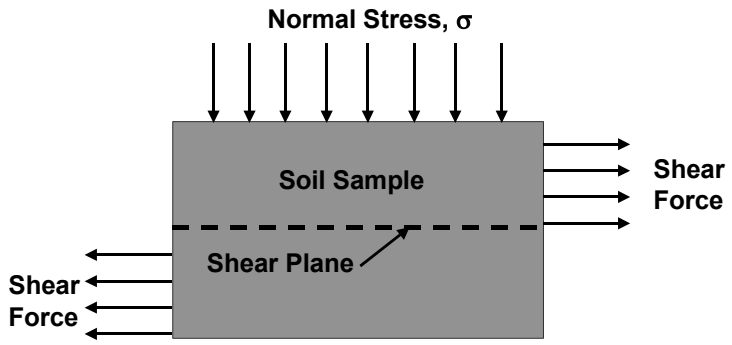
Slide 4-45

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***

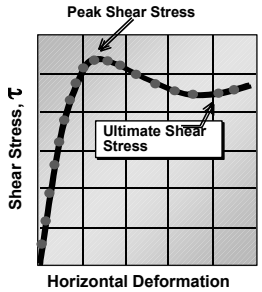
Slide 4-46

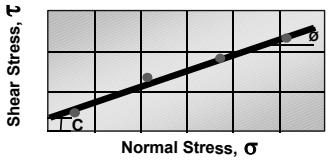
Direct Shear Test



Slide 4-47

Direct Shear Test Typical Results





Slide 4-48

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 4-49

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 4-50

Lab Testing by Consultants

- ***Prepare Specific Testing Program to be Accomplished***
- ***Perform Check Testing on Random Samples***
- ***Use AMRL Certified Labs***

Slide 4-51

SOILS AND FOUNDATIONS WORKSHOP

Site Exploration

Basic Soil Properties

Laboratory Testing

- ***P_o Diagram***
- ***Test Request***
- ***Consolidation Results***
- ***Strength Results***

Slope Stability

Embankment Settlement

Spread Footing Design

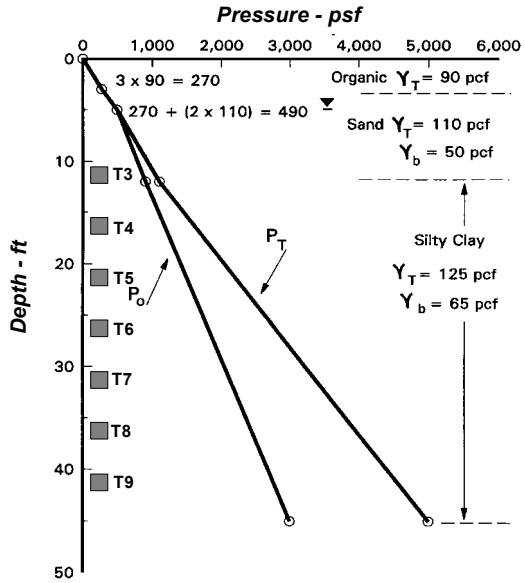
Pile Design

Construction Aspects

Slide 4-52

SOILS AND FOUNDATIONS WORKSHOP

Apple Freeway
Pressure Diagram UDH BAF-4



Slide 4-53

SOILS AND FOUNDATIONS WORKSHOP

SOIL MECHANICS LABORATORY TEST REQUEST

PROJECT I-O APPLE FREEWAY PROJ. NO. _____ HOLE NO. BAF-4
DATE 6-3-92 REQUEST BY _____ APPROVED BY _____ STATION 93+27 OFFSET 50' LT.
ORIGINAL REQUEST ☒ SUPPLEMENTAL REQUEST ☐

CONSOLIDATION TESTS							STRENGTH TESTS													SPECIAL AND ADDITIONAL TESTS**	
SAMPLE NUMBER	MACHINE CAPACITY	RELOAD FOR Cv	LOAD TIME	RECYCLE	*STATUS		SAMPLE NUMBER	SAMPLE DIAM. 1.4"	SAMPLE DIAM. 2.8"	TYPE OF TEST AND CONSOLIDATION PRESSURE U	UU	CONF. PRESS (PSI)	CU	CONS. PRESS (PSI) 1	2	3	*STATUS	% ORG.	% INERT	
T3	32K	500	3 hr.	Yes			T4		FULL		✓									
T4		1000		Yes			T4	✓					✓							
T5				No			T5		FULL		✓									
T6				Yes			T5	✓					✓							
T7				No			T6		FULL		✓									
T9				No			T6	✓					✓							
							T7		FULL		✓									
							T7	✓					✓							
							T9		FULL		✓									
							T9	✓					✓							

ADDITIONAL REQUESTS: CONSOLIDATION TESTS - SPECIFIC GRAVITY ON ALL TESTS
STRENGTH TESTS - ATTERBURG LIMITS AND HYDROMETER ON ALL TESTS

* CHECK MARK WHEN TEST IS PUT IN PROGRESS ✓ ; CIRCLE WHEN COMPLETED ⓒ ; CROSS HATCH WHEN COMPUTED ⊗
** TO SUPPLEMENT ROUTINE CLASSIFICATION TESTS ON CONSOLIDATION AND STRENGTH TEST SAMPLES.

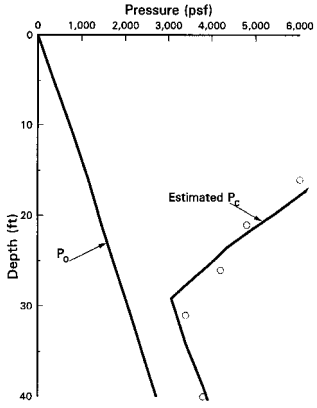
Slide 4-54

SOILS AND FOUNDATIONS WORKSHOP

CONSOLIDATION TEST RESULTS SUMMARY

Hole UDH BAF-4

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



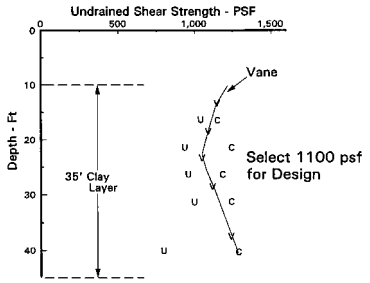
Slide 4-55

SOILS AND FOUNDATIONS WORKSHOP

SHEAR STRENGTH TEST RESULTS SUMMARY

Hole UDH BAF-4

Depth Ft.	Tube No.	w %	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 4-56

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 4-57

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***

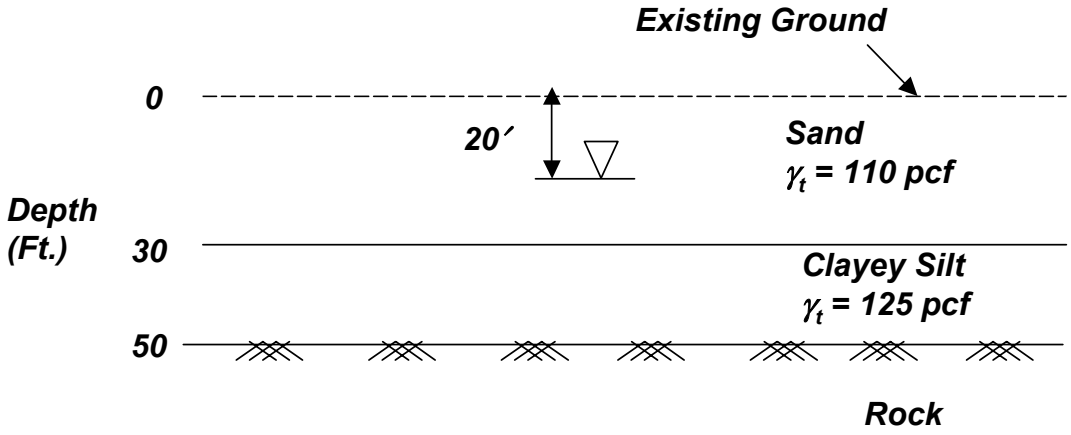
Activity: Compute and Diagram Total and Effective Pressures

Slide 4-58

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:

LESSON 5

TOPIC 1

Slope Stability

SLOPE STABILITY

Lesson 5 - Topic 1

Slide 5-1-1

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

Embankments: Major Design Considerations

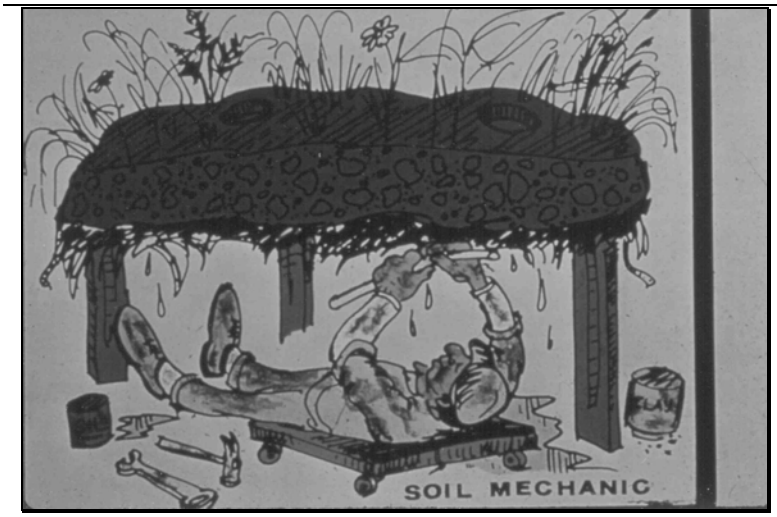
- ***Stability***
- ***Settlement***
- ***Effects on the Structure***

Slide 5-1-3

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

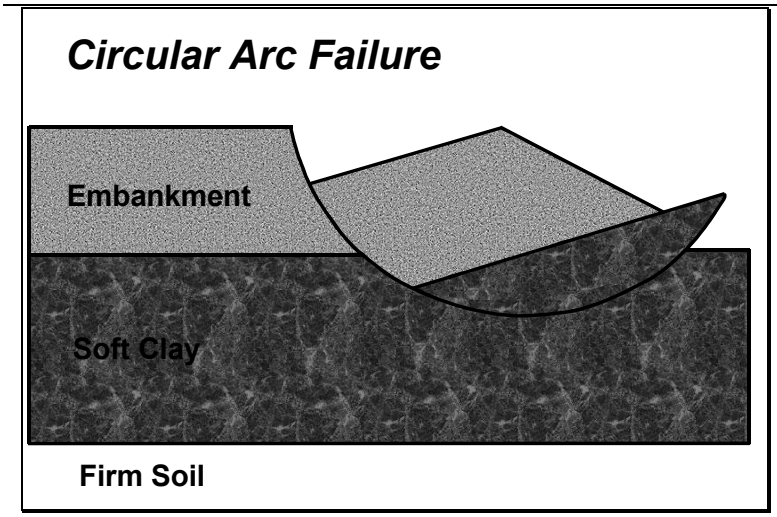


Slide 5-1-5

Major Stability Problems

Circular and Sliding Block Failures

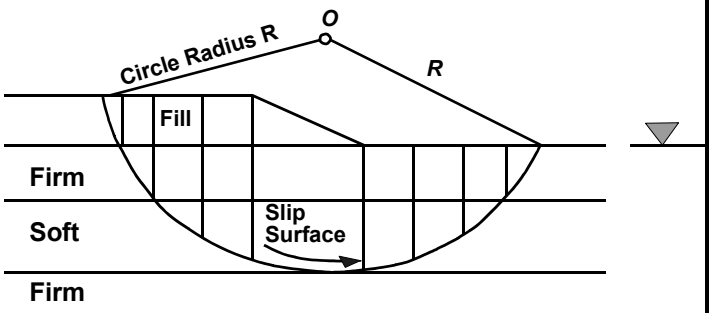
Slide 5-1-6



Slide 5-1-7

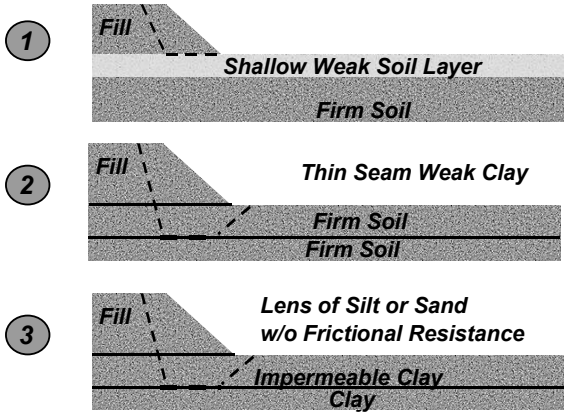
Slide 5-1-8

Circular Arc Stability Analysis

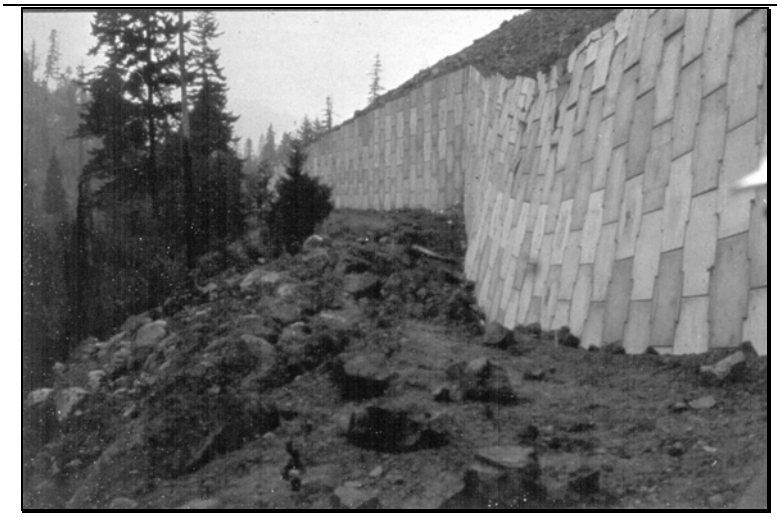


Slide 5-1-9

Sliding Block Failure Types

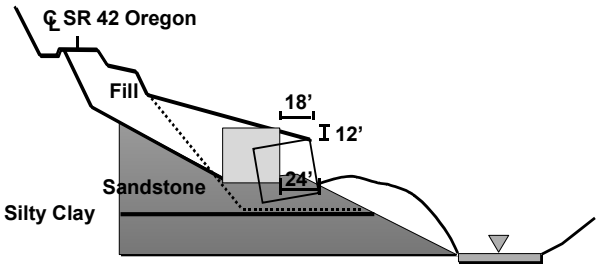


Slide 5-1-10



Slide 5-1-11

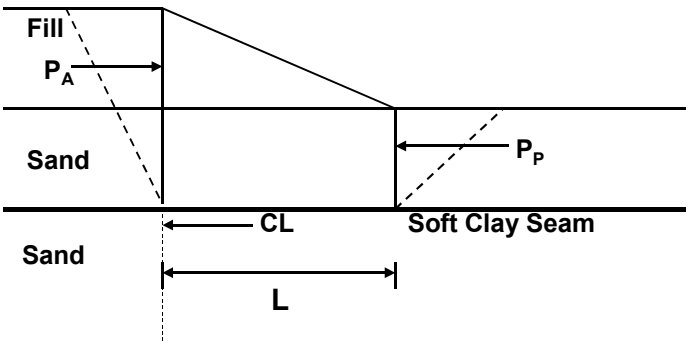
After Slide



Slide 5-1-12

Slide 5-1-13

Sliding Block Analysis



Slide 5-1-14

Effect of Water on Slope Stability

- ***Frictional Soils***
  - ***Below Water Table, Buoyancy Reduces Shearing Resistance***
- ***Clays***
  - ***Cohesive Strength Decreases as Moisture Content Increases***

Slide 5-1-15

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

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

Embankments: Recommended Safety Factors

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

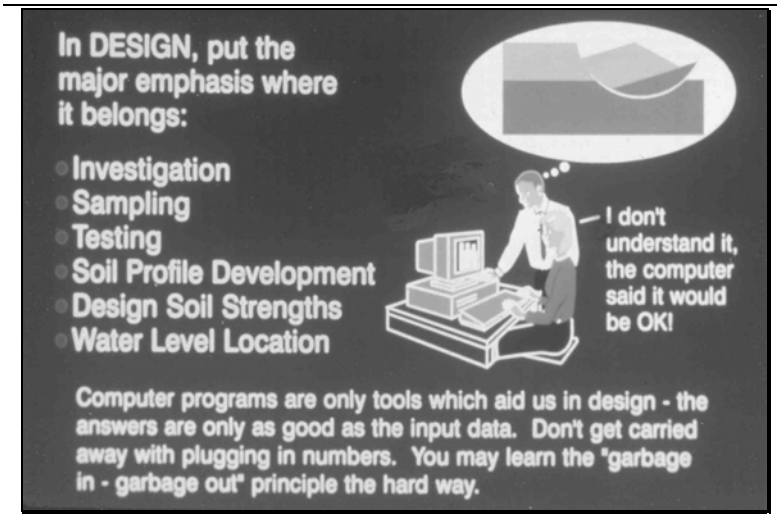
- ***End Slope Conditions***
  - ***Minimum Safety Factor = 1.30***
- ***Side Slope Conditions***
  - ***Minimum Safety Factor = 1.25***

Slide 5-1-18

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



Slide 5-1-20

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Failure Analysis Methods

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

Slide 5-1-21

SOILS AND FOUNDATIONS WORKSHOP

$$F.S. = \frac{\Sigma\ Resisting\ \ Moments}{\Sigma\ Driving\ \ Moments}$$

$$= \frac{\Sigma\ N\ Tan\phi\ R + \Sigma\ Cl\ R}{\Sigma\ T\ R}$$

$$\therefore F.S. = \frac{\Sigma\ Resisting\ \ Forces}{\Sigma\ Driving\ \ Forces}$$

$$= \frac{\Sigma\ N\ Tan\phi + \Sigma\ Cl}{\Sigma\ T}$$

Slide 5-1-22

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Analysis for Factor of Safety

The Rule of Thumb is:

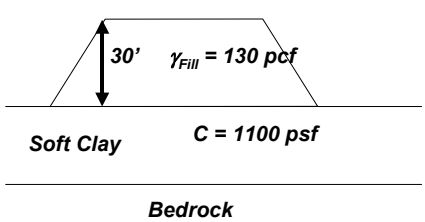
$$\textit{Factor of Safety } (F.S.) = \frac{6C}{\gamma_{Fill} \times H_{Fill}}$$

Where: C = Cohesive Strength of Clay (psf)
γ_{Fill} = Fill Soil Unit Weight (pcf)
H_{fill} = Fill Height (ft.)

Slide 5-1-23

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Analysis Rule of Thumb Example



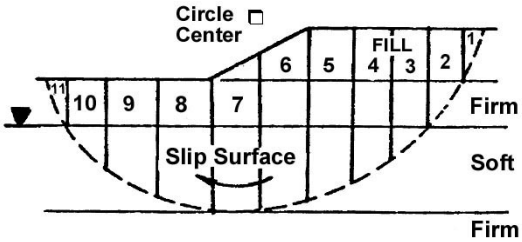
$$F.S. = \frac{(6)(1100)}{(130)(30)} = 1.69$$

Slide 5-1-24

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Failure Normal Method of Slices - Computation by Hand

1. ***Draw Cross Section to Natural Scale***
2. ***Select Failure Surface***
3. ***Divide Mass into 10-15 Vertical Slices***

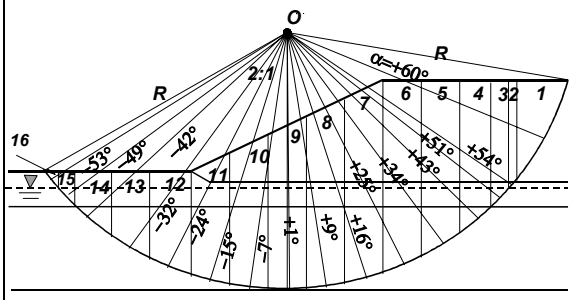


Slide 5-1-25

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Analysis

Extend rays from circle center "O" to the failure surface at the projected centroid of each slice



Note that slices 1 through 9 have positive α angles and contribute to the driving force. Slices 10 through 16 have negative α angles and reduce the net driving force.

Slide 5-1-26

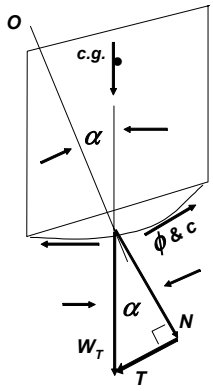
SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Computation by Hand

4. ***Compute Total Weight (W_T) of Each Slice***
5. ***Compute Resisting Forces: N Tanϕ - μl (Frictional) and Cl (Cohesive) for Each Slice***
6. ***Compute the Tangential Driving Force (T).***

Slide 5-1-27

SOILS AND FOUNDATIONS WORKSHOP



Forces on One Slice <u>No Water</u>

	(Forces)
NTan ϕ →	*(Resisting)*
Cl →	*(Resisting)*
← T	*(Driving)*

C = Cohesion along slice base

Tan ϕ = Coefficient of friction along slice base

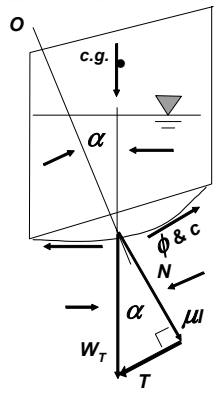
W_T = Total slice weight

T = W_T Sin α

N = W_T Cos α

Slide 5-1-28

SOILS AND FOUNDATIONS WORKSHOP



Forces on One Slice <u>With Water</u>

	(Forces)
$N\tan\phi$ →	*(Resisting)*
Cl →	*(Resisting)*
← T	*(Driving)*

μ = Water pressure on slice base

= Avg. $h_{water} \times \gamma_w$

μl = Water uplift force

W_T = Total slice weight

(use γ_{Total} both above and below W.T.)

Note $\rightarrow N = W_T \cos\alpha - \mu l$

$T = W_T \sin\alpha$

Slide 5-1-29

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Computation by Hand

7. Sum Resisting and Driving Forces for All Slices and Compute Safety Factor (F.S.)

Slide 5-1-30

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Example for One Slice with No Water

Assume:

- ***γ_{total} = 120 pcf, slice height = 10', slice width = 10', ϕ = 25°, α = 20°, l =11', C = 200 psf.***
- ***Find: Resisting and Driving Forces***

Slide 5-1-31

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Example Solution

$W_T = \gamma_{total}$ x slice area (x 1' thick)
= 120 pcf x 10' x 10'
= 12000 lbs

$N = W_T \cos \alpha - \mu l$
= 12000 lbs x Cos 20°
= 11276 lbs

Slide 5-1-32

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Example Solution (Cont'd)

N Tan ϕ = 11276 x Tan 25°
= 5258 lbs

Cl = 200 psf x 11' x 1'
= 2200 lbs

T = W_t Sin α
= 12000 lbs x Sin 20°
= 4104 lbs

Slide 5-1-33

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices Group Exercise

Assuming the water is 5' above the slice base, which of the force components change in this exercise?

Slide 5-1-34

SOILS AND FOUNDATIONS WORKSHOP

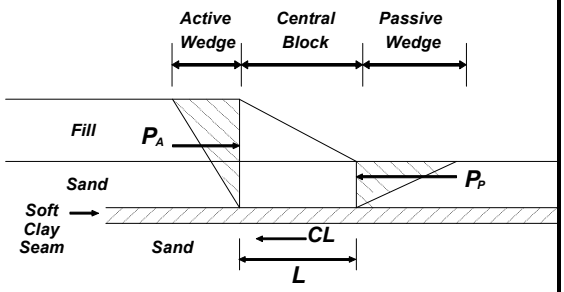
Sliding Block Failure Analysis Methods

- ***Hand Solution***
- ***Computer Solution***

Slide 5-1-35

SOILS AND FOUNDATIONS WORKSHOP

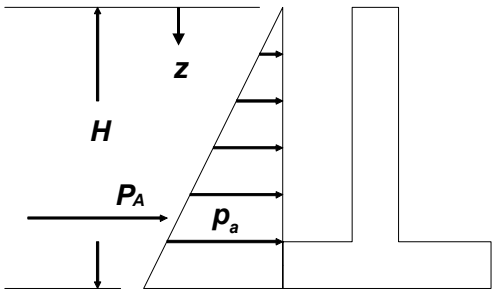
SLIDING BLOCK ANALYSIS



Slide 5-1-36

SOILS AND FOUNDATIONS WORKSHOP

Active Earth Pressure



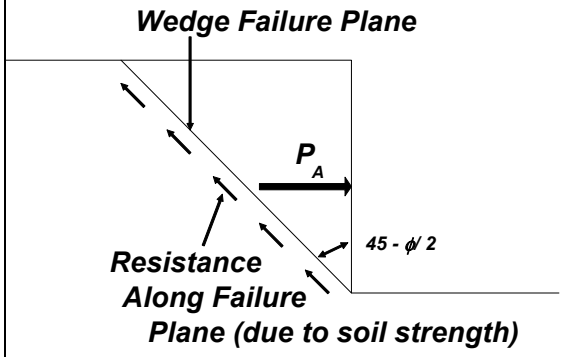
$P_a = K_A \gamma z$

$PA = ½ \gamma H^2 K_A$ (Active Force)

Slide 5-1-37

SOILS AND FOUNDATIONS WORKSHOP

Active Earth Pressure



P_A = Net Force Against the Central Block

$P_A = 1/2\ \gamma H^2 K_A$ (Active Force)

Slide 5-1-38

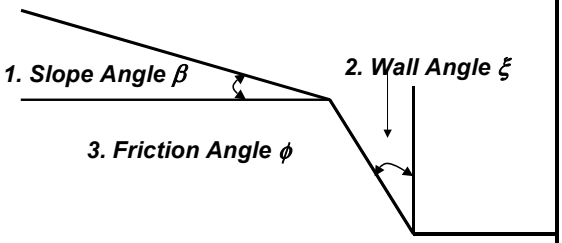
SOILS AND FOUNDATIONS WORKSHOP

Active Earth Pressure

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

(For $\beta = 0$, $\xi = 0$)

K_A varies with:

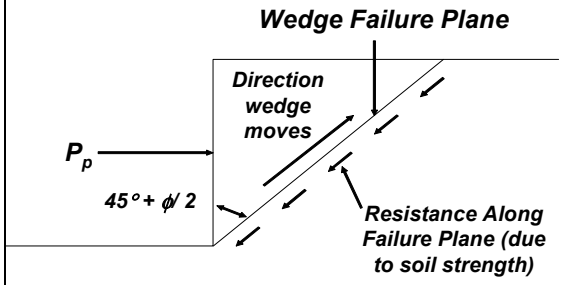


If ξ or $\beta \neq 0$, compute K_A from formulas or charts in soils textbooks

Slide 5-1-39

SOILS AND FOUNDATIONS WORKSHOP

Passive Earth Pressure



P_P = <u>Passive</u> Force

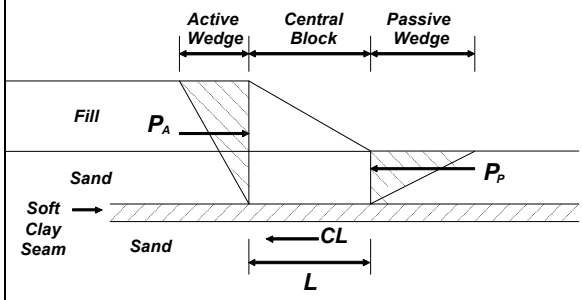
$P_P = ½ \gamma H^2 K_P$

$K_P = Tan2 (45° + \phi / 2)$
(If $\beta = 0$, $\xi = 0$)

Slide 5-1-40

SOILS AND FOUNDATIONS WORKSHOP

SLIDING BLOCK ANALYSIS



P_A = Active Driving Force = $\frac{1}{2}\gamma H^2 K_A$

P_P = Passive Resisting Force = $\frac{1}{2}\gamma H^2 K_P$

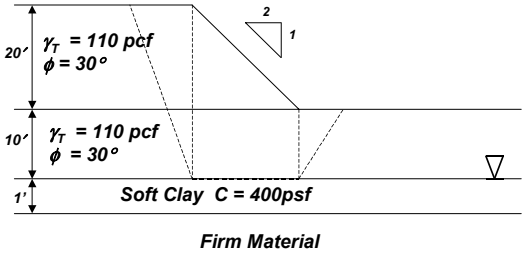
CL = Resisting Force Due To Clay Cohesion

$$F.S. = \frac{\text{Resisting Forces}}{\text{Driving Forces}} = \frac{P_P + CL}{P_A}$$

Slide 5-1-41

SOILS AND FOUNDATIONS WORKSHOP

Example 5.1: Find the Safety Factor For The 20´High Embankment By The Simple Sliding Block Method Using Rankine Pressure Coefficients, for the Slope Shown Below.



Slide 5-1-42

SOILS AND FOUNDATIONS WORKSHOP

Solution:

Step 1: Compute Driving Force (P_A)

- ***Active Driving Force (P_a) (consider a 1 ft. wide strip of the embankment)***

$$P_A = \frac{1}{2}\gamma_T H^2 K_A$$

(Use γ_T as the water table is below the failure plane)

$$K_A = Tan^2(45 - \frac{\phi}{2}) = Tan^2(45 - \frac{30}{2}) = 0.33$$

$$P_A = \frac{1}{2}(0.110\ kcf)(30')^2(0.33)(1') = 16.5K$$

Slide 5-1-43

SOILS AND FOUNDATIONS WORKSHOP

Solution (cont'd):

Step 2: Compute Resisting Force (CI & P_p)

- *Central Block Resistance (CI)*

$$CI = (0.400\ ksf)(40')(1') = 16.0K$$

- *Passive Resisting Force (P_p)*

$$P_p = \frac{1}{2}\gamma_T H^2 K_p$$

$$K_p = Tan^2(45 + \frac{\phi}{2}) = Tan^2(45 + \frac{30}{2}) = 3.0$$

$$P_p = (\frac{1}{2})(0.110\ kcf)(10)^2(3.0)(1') = 16.5K$$

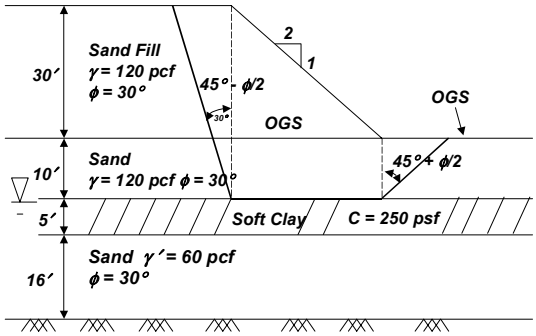
$$Safety\ Factor = \frac{CI + P_p}{P_A} = \frac{16.0K + 16.5K}{16.5K} = 1.97$$

Slide 5-1-44

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.

Slide 5-1-45

SOILS AND FOUNDATIONS WORKSHOP

Slope Stability

- ***Compute Resisting and Driving forces***
- ***Explain the Effects of Water Pressure on Frictional Resistance***

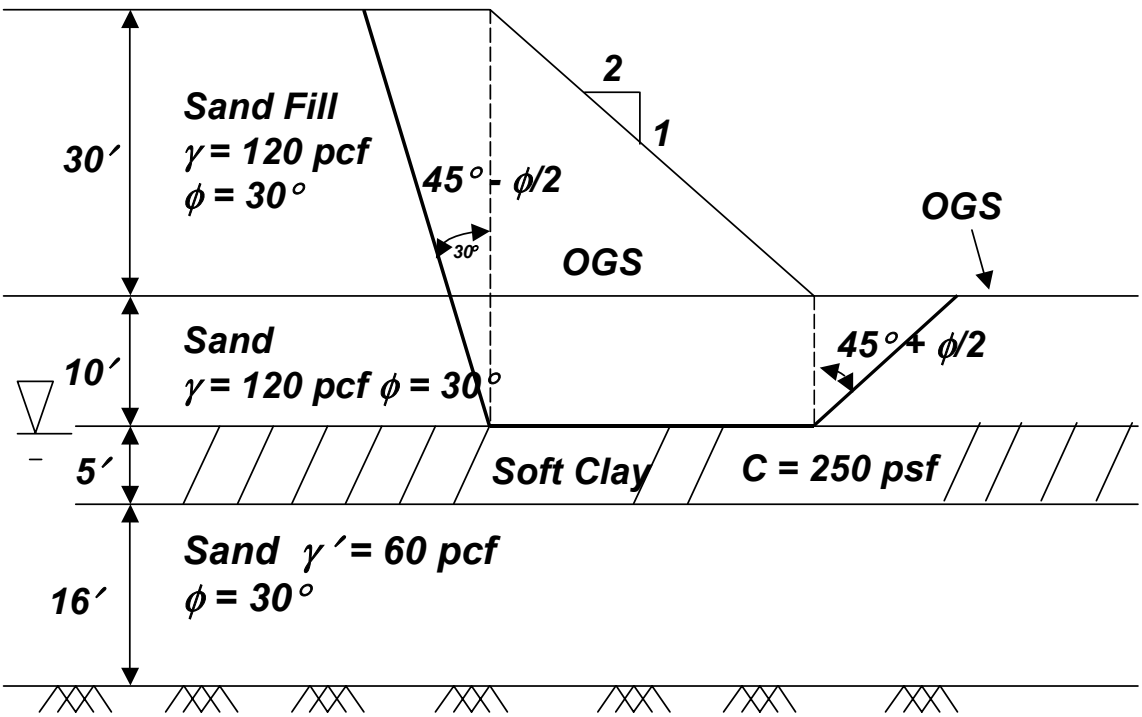
Activities: Circular Arc
Sliding Block

Slide 5-1-46

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.

LESSON 5

TOPIC 2

Solutions to Slope Instability

SOLUTIONS TO SLOPE INSTABILITY

Lesson 5 - Topic 2

Slide 5-2-1

SOLUTIONS TO SLOPE INSTABILITY

1. Discuss Solutions to Stability Problems

ACTIVITIES: Stability Problem Solving

Slide 5-2-2

Solutions to Slope Stability Problems

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

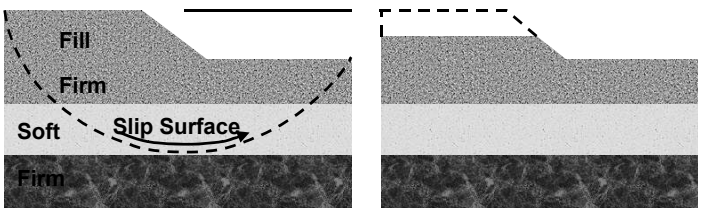
Slide 5-2-3

Solutions to Slope Stability Problems (Cont'd)

- ***Stage Construct Fill***
- ***Displace Weak Soil***
- ***Ground Improvement***
- ***Lightweight Fill***

Slide 5-2-4

Reduce Grade



Foundation Overstressed **Reduced Load**

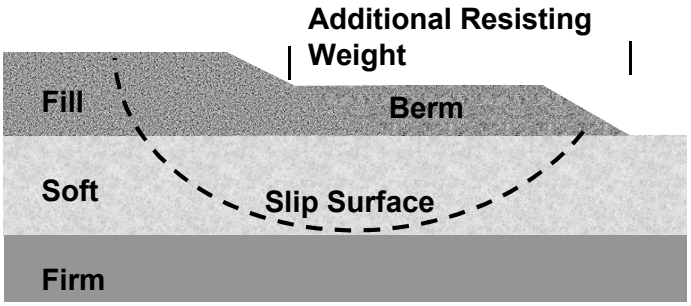
Effect: Reduces Driving Weight

Slide 5-2-5

Slide 5-2-6

Slide 5-2-7

Counter Berm

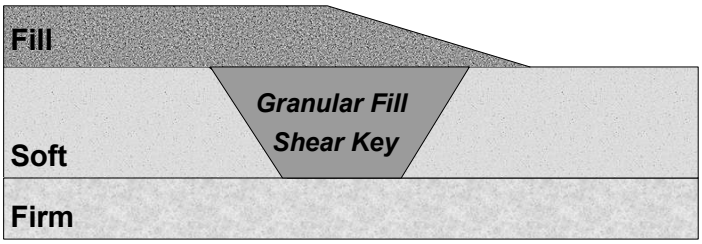


Effect: Provides Resisting Weight

Slide 5-2-8

Slide 5-2-9

Excavate and Replace Weak Soil

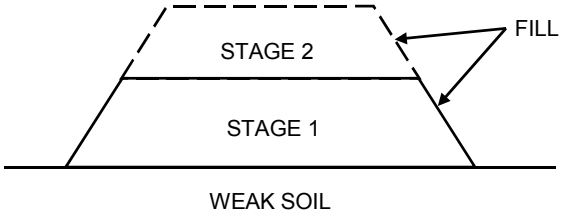


Effect: Stronger Soil Resists Sliding

Slide 5-2-10

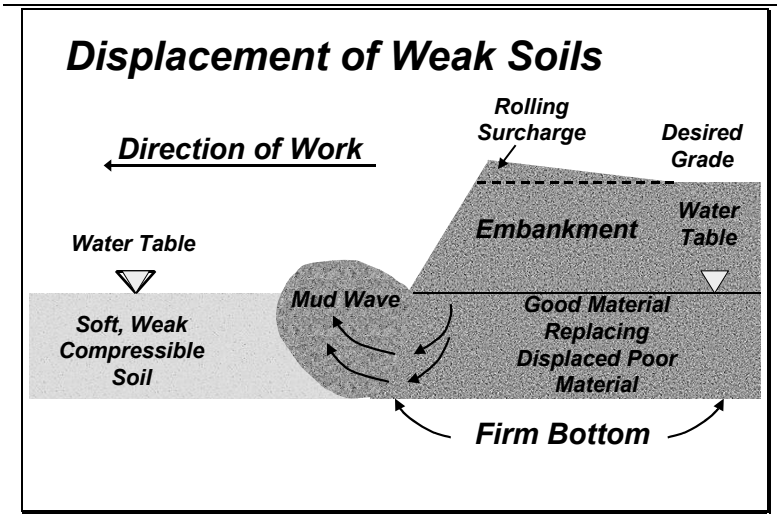
Slide 5-2-11

Fill Stage Construction

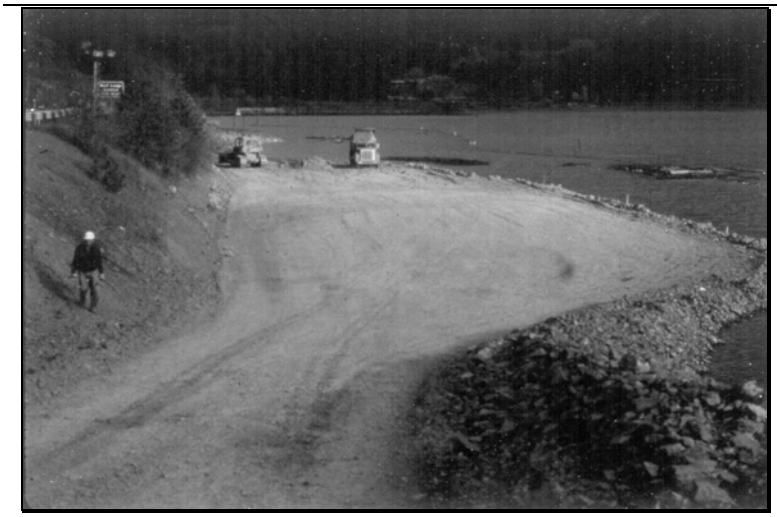


Slide 5-2-12

Slide 5-2-13



Slide 5-2-14



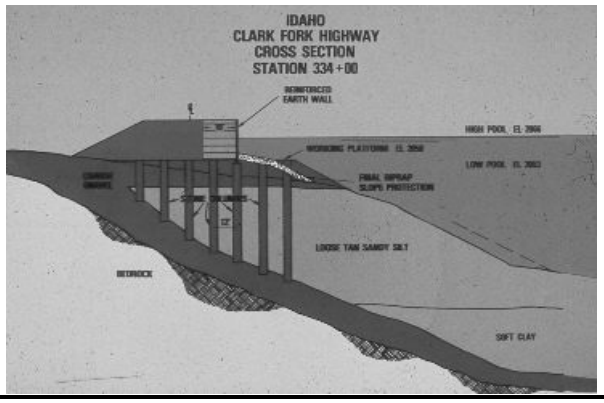
Slide 5-2-15

Ground Improvement

- ***Grouting***
- ***Vertical Wick Drains***
- ***Stone Columns***
- ***Vibro Compaction***
- ***Dynamic Compaction***
- ***Soil Mixing***
- ***Soil Nailing***
- ***Reinforced Soil Slopes***
- ***Micropiles***

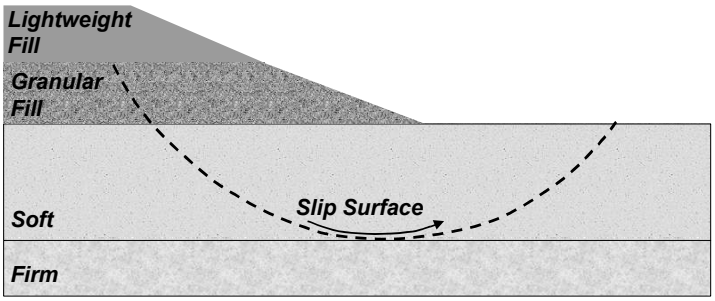
Slide 5-2-16

Ground Improvement Stone Columns



Slide 5-2-17

Lightweight Fill



Effect: Reduce Driving Weight

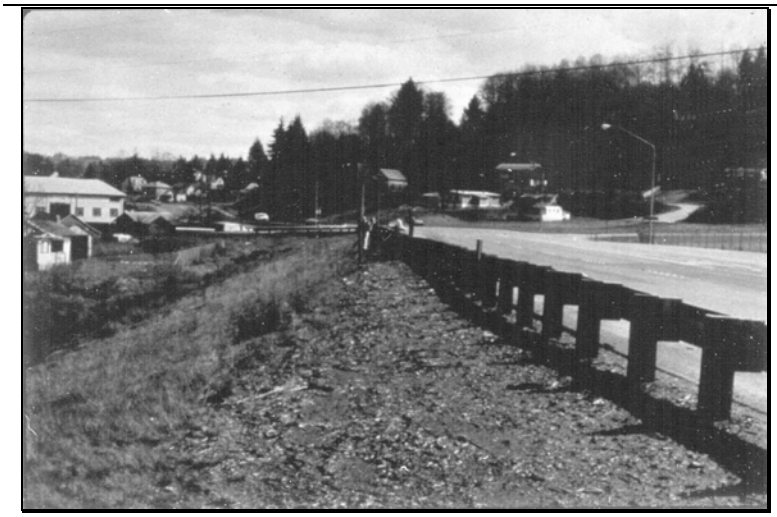
Slide 5-2-18

Examples of Lightweight Fill Materials

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

Slide 5-2-19

Slide 5-2-20



Slide 5-2-21

Slide 5-2-22

Slide 5-2-23

Slide 5-2-24

Slide 5-2-25

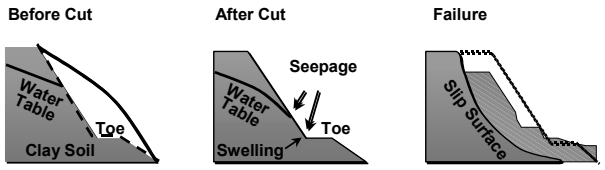
Slide 5-2-26

Cut Slope Stability

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

Slide 5-2-27

Cut Slope Stability



Undrained Clay in Cut Gradually Weakens And May Fail Long After Construction

Slide 5-2-28

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

Slide 5-2-30

Slide 5-2-31

Slide 5-2-32

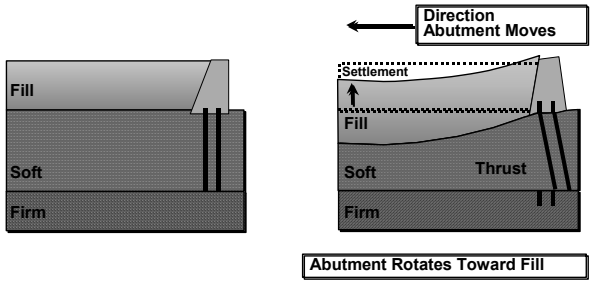
Cut Slopes

Minimum Recommended Safety Factor = 1.50

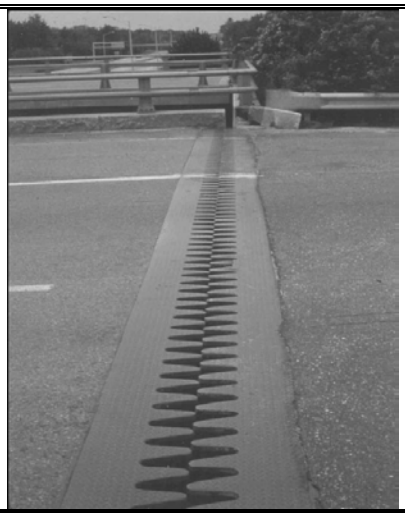
Cut Slopes may Deteriorate With Time as a Result of Natural Drainage Conditions That Embankments Do Not Experience

Slide 5-2-33

Lateral "Squeeze" of Soft Subsoil



Slide 5-2-34



Slide 5-2-35

Slide 5-2-36

Lateral Squeeze: Abutment Rotation Can Occur if:

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

Slide 5-2-37

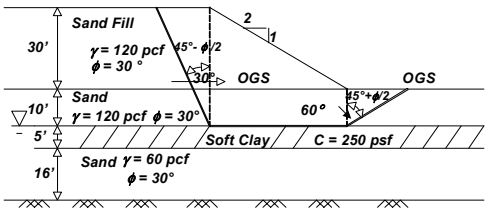
Lateral Squeeze: How to Prevent Abutment Rotation

Get Fill Settlement Out Before Abutment Piling are Driven

Slide 5-2-38

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

SOILS AND FOUNDATIONS WORKSHOP

SOLUTIONS TO SLOPE INSTABILITY

- ***Discuss Solutions to Stability Problems***

Activities: Stability Problem Solving

Slide 5-2-40

SOILS AND FOUNDATIONS WORKSHOP

Site Exploration

Basic Soil Properties

Laboratory Testing

Slope Stability

Circular Arc
Sliding Block
Lateral Squeeze

Embankment Settlement

Spread Footing Design

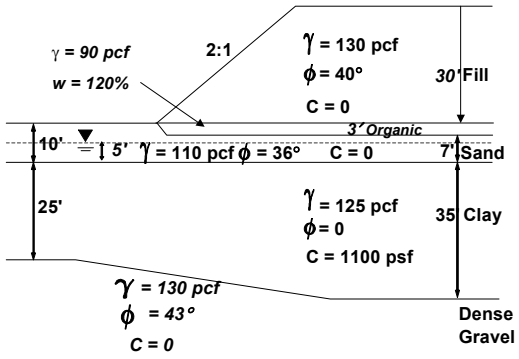
Pile Design

Construction Aspects

Slide 5-2-41

SOILS AND FOUNDATIONS WORKSHOP

WORKSHOP DESIGN PROBLEM
APPROACH EMBANKMENT STABILITY
DESIGN SOIL PROFILE



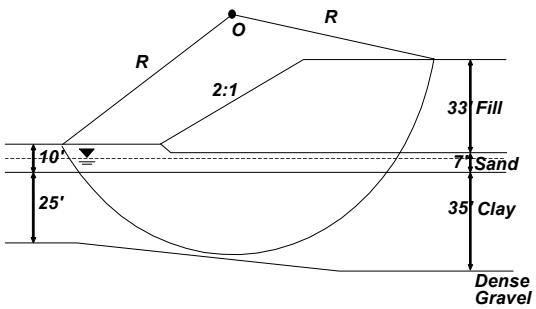
Estimate the safety factor and the need for a more detailed analysis.

Slide 5-2-42

SOILS AND FOUNDATIONS WORKSHOP

Compute F.S. Against Circular Arc Failure by

Normal Method (Hand Solution)



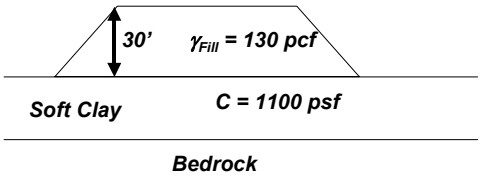
For deep clay subsoil the "critical" (Min. F.S.) failure surface will generally pass deep into the weakest clay layer. The center of the circle usually lies above the fill slope

Slide 5-2-43

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Analysis Rule of Thumb for Factor of Safety

$$\text{Factor of Safety (F.S.)} = \frac{6C}{\gamma_{Fill} \times H_{Fill}}$$

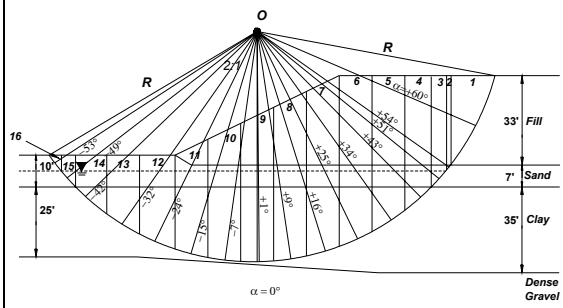


$$F.S. = \frac{(6)(1100)}{(130)(30)} = 1.69$$

Slide 5-2-44

SOILS AND FOUNDATIONS WORKSHOP

Compute F.S. Against Circular Arc Failure by Normal Method (Hand Solution)



Note that slices 1 through 9 have positive α angles and contribute to the driving force. Slices 10 through 16 have negative α angles and reduce the net driving force.

Slide 5-2-45

SOILS AND FOUNDATIONS WORKSHOP

Workshop Design Problem

Slice No.	W_T (lb)	l (ft)	α (deg)	c (psf)	φ (deg)	μ (psf)	μl (lb)	$W_T \cos\alpha$ (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	48,955
6	93,720	15	25	1100	0	-	-	-	-	0	16,500	39,608
7	95,790	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

C = cohesion intercept
φ = friction angle
μ = pore pressure
W_T = total wt. of slice (soil + water)

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

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

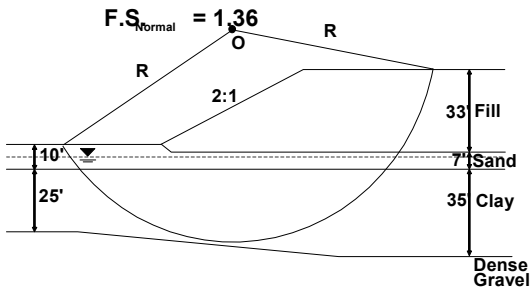
TABULAR FORM FOR CALCULATING F.S. BY NORMAL METHOD OF SLICES

Slide 5-2-46

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices

Hand Solution



Workshop Design Problem

APPLE FREEWAY - E. APPROACH EMB.

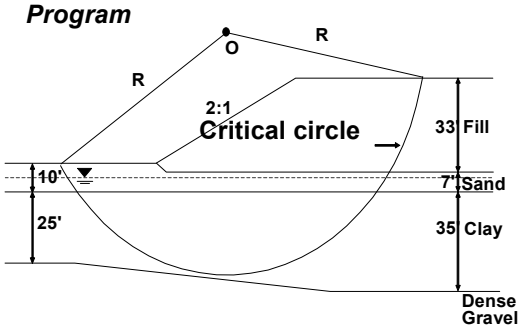
Slide 5-2-47

SOILS AND FOUNDATIONS WORKSHOP

Comparison of Factors of Safety

F.S. = 1.36 Normal Method - Hand Solution

F.S. = 1.63 Bishop Method - Computer Program



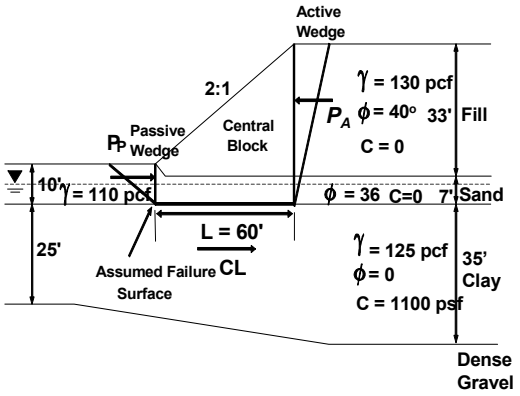
Remember the Normal Method is very conservative when the soil profile has frictional soil and the Bishop method is more theoretically correct.

Slide 5-2-48

SOILS AND FOUNDATIONS WORKSHOP

Sliding Block Analysis

Estimate F.S. Against Sliding Block Type Failure along top of Clay Layer for Assumed Failure Surface Shown.



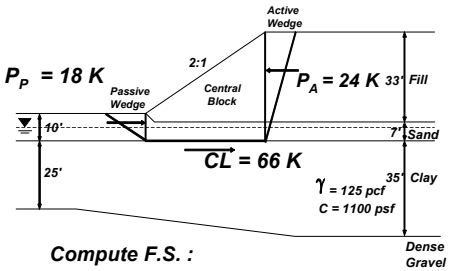
APPLE FREEWAY - EAST APPROACH EMB.

Slide 5-2-49

SOILS AND FOUNDATIONS WORKSHOP

Sliding Block Analysis

APPLE FREEWAY - E. APPROACH EMB.



Compute F.S. :

$$F.S. = \frac{\text{Horiz. Resisting Forces}}{\text{Horiz. Driving Forces}}$$

$$\frac{18\ K + 66\ K}{24\ K} = \frac{84\ K}{24\ K} = 3.5\ (O.K.)$$

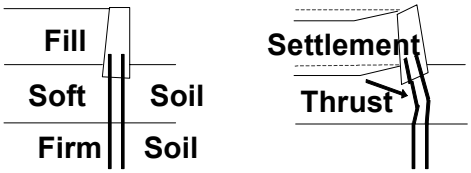
Circular Arc Failure More Critical

Slide 5-2-50

SOILS AND FOUNDATIONS WORKSHOP

Lateral Squeeze

Unbalanced fill load squeezes soil laterally.



Assumed ***Actual***

If $\gamma_{Fill} \times H_{Fill} > 3 \times Cohesion$

then lateral squeeze can occur.

Slide 5-2-51

SOILS AND FOUNDATIONS WORKSHOP

Lateral Squeeze

Apple Freeway - E. Approach Emb.

Lateral squeeze occurs if:

$\gamma_{Fill} \times H_{Fill} > 3 \times Cohesion$

For east abutment:

130 pcf x 30 ft > 3 x 1100 psf

3900 psf > 3300 psf

Lateral squeeze <u>can</u> occur

Don't construct abutment until settlement is complete (U90%).

Slide 5-2-52

SOILS AND FOUNDATIONS WORKSHOP

Embankment Stability

Design Soil Profile

Soil layer unit weights and strengths estimated

Circular Arc Analysis

Approach embankment safety factor 1.63 against circular failure

Sliding Block Analysis

Approach embankment safety factor 3.5 against sliding failure

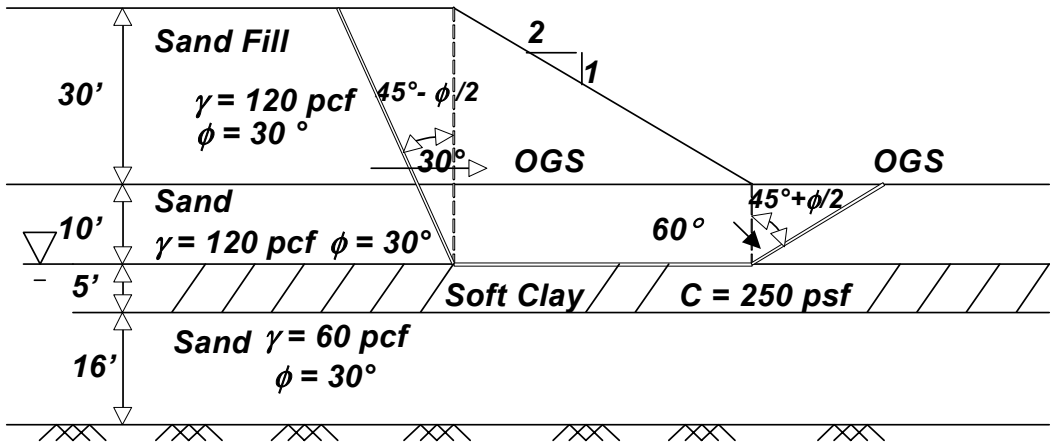
Lateral Squeeze

Possible abutment rotation

Slide 5-2-53

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.

LESSON 6

TOPIC 1

Embankment Settlement

EMBANKMENT SETTLEMENT

Lesson 6 - Topic 1

Slide 6-1-1

EMBANKMENT SETTLEMENT

1. Estimate Compressibility from Basic Soils Data

2. Calculate Settlement

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

Slide 6-1-2

Embankments
Major Design Considerations

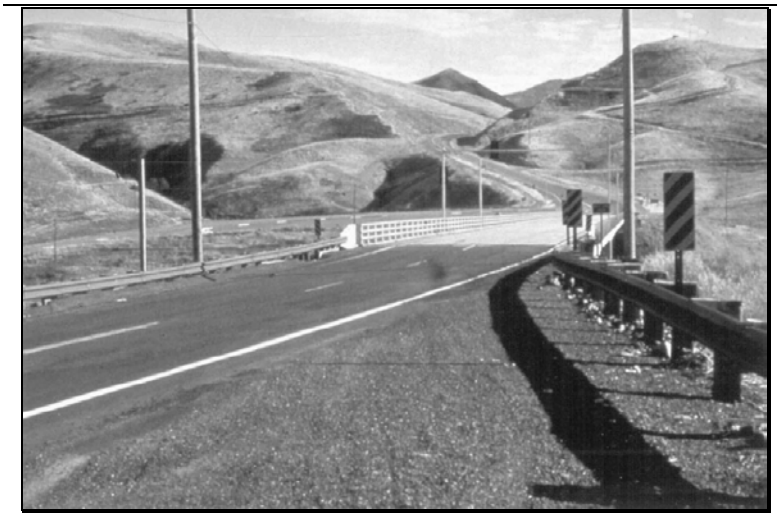
- ***Stability***
- ***Settlement***
- ***Effects on the Structure***

Slide 6-1-3

Embankments

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

Slide 6-1-4



Slide 6-1-5

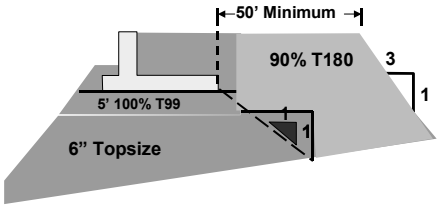
Avoid Settlement Within Embankment

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

Slide 6-1-6

To Eliminate Settlement Within Embankment

Suggested Approach Embankment Details

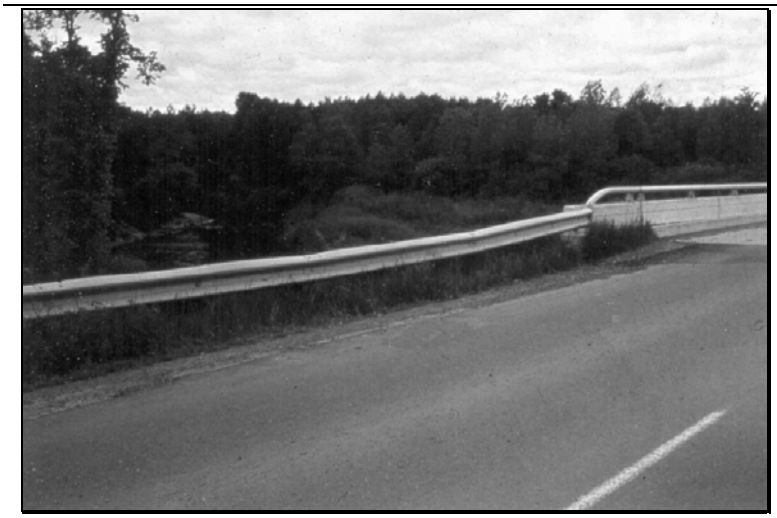


Highway Embankment Material 6" Topsize (95% T180)

Highway Embankment Material (90% T180)

Select Structure Fill (100% T99)

Slide 6-1-7



Slide 6-1-8

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***

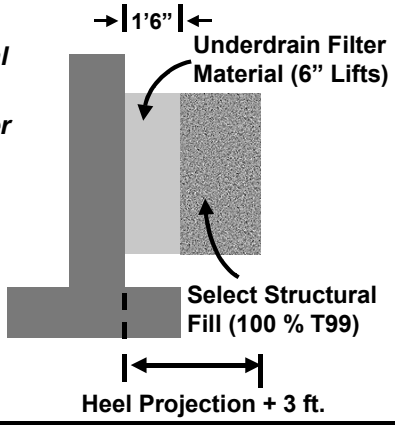
Slide 6-1-9

Slide 6-1-10

Slide 6-1-11

To Prevent Bump at End of Bridge

- ***Use Select Structural Fill***
- ***Use Underdrain Filter Material***
- ***Use Durable Well Graded Granular for High Density w/Min. Compactive Effort***



Slide 6-1-12

Select Material Specifications

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

Slide 6-1-13

Select Material Specification (Cont’d)

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

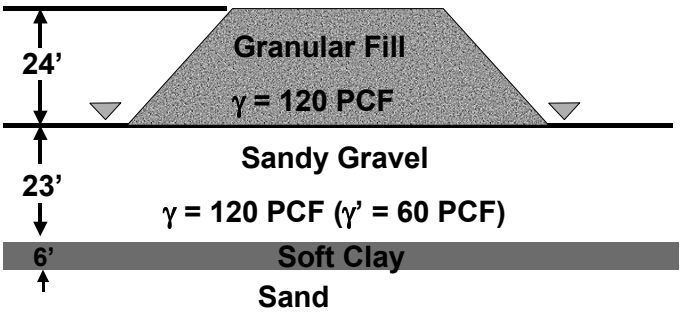
Slide 6-1-14

Avoid Major Subsoil Settlement

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

Slide 6-1-15

Settlement Problem



Slide 6-1-16

Settlement

- ***Amount***
- ***Time***

Slide 6-1-17

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 6-1-18

Settlement Time

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

Where: t = Time for Settlement

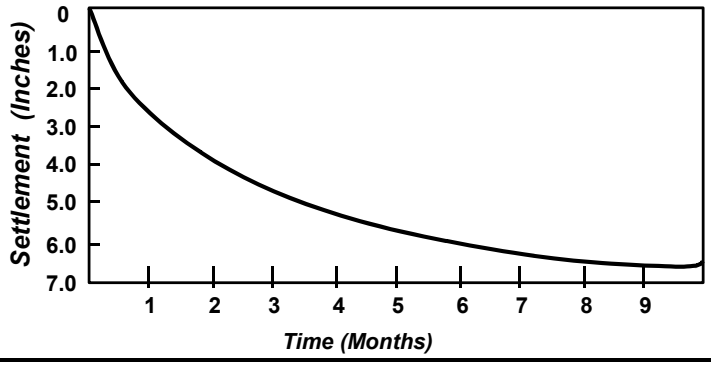
T = Time Factor

H_v = Vertical Drainage Path Length

C_V = Coefficient of Consolidation

Slide 6-1-19

Embankment on Clay Subsoil Time-Settlement Curve



Slide 6-1-20

SOILS AND FOUNDATIONS WORKSHOP

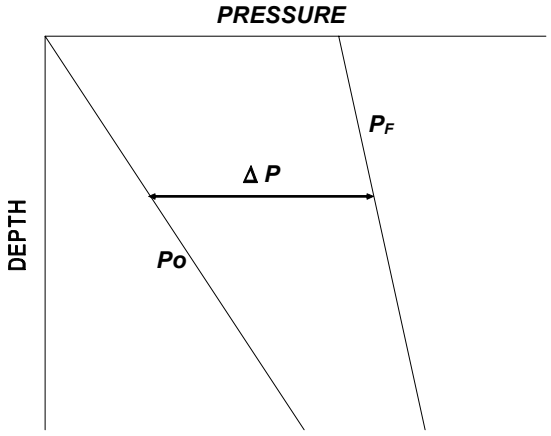
Estimate of Embankment Settlement Due to Consolidation of Subsoil

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

Slide 6-1-21

SOILS AND FOUNDATIONS WORKSHOP

Po Diagram



Po = Effective overburden pressure before fill placed

Δ P = Pressure increase due to approach emb. load (determined using pressure distribution chart)

P_F = Po + ΔP = Final pressure felt by subsoil

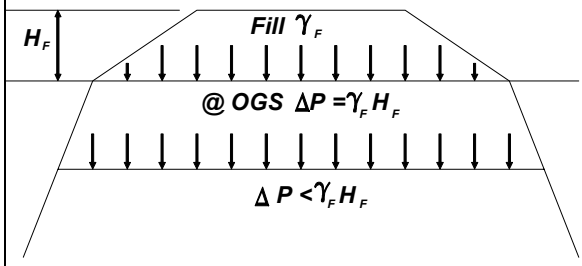
Slide 6-1-22

SOILS AND FOUNDATIONS WORKSHOP

PRESSURE DISTRIBUTION OF EMBANKMENT LOAD

Addition of Embankment Load is What Causes Consolidation of Subsoil

The Embankment Load Spreads Out with Depth ->ΔP Decreases with Depth



Can Use Pressure Distribution Chart To Compute ΔP with Depth

Slide 6-1-23

SOILS AND FOUNDATIONS WORKSHOP

Case of Long Strip-Uniform Loading Vertical Pressures at End of Fill

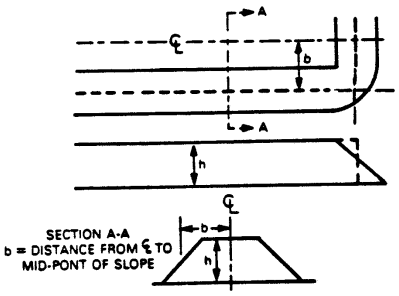
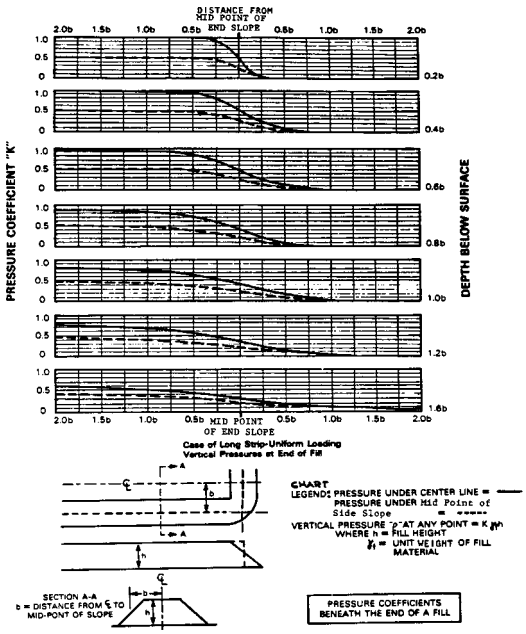


CHART
LEGEND: PRESSURE UNDER CENTER LINE = ——
PRESSURE UNDER Mid Point of Side Slope = •••••
VERTICAL PRESSURE "ρ" AT ANY POINT = $K \gamma_f h$
WHERE h = FILL HEIGHT
γ_f = UNIT WEIGHT OF FILL MATERIAL

Slide 6-1-24

SOILS AND FOUNDATIONS WORKSHOP



Slide 6-1-25

SOILS AND FOUNDATIONS WORKSHOP

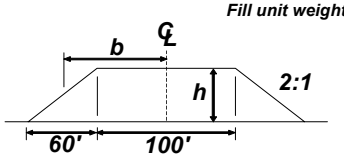
USE OF PRESSURE DISTRIBUTION CHART EXAMPLE

Given: *Fill height, h = 30 ft*

End and side slopes, 2:1

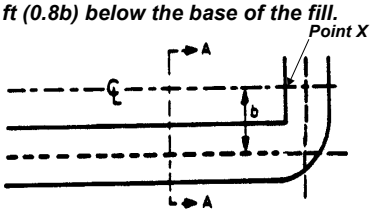
Embankment top width = 100 ft

Fill unit weight γ_F = 100 pcf



b = 100/2 + 60/2
b = 80'

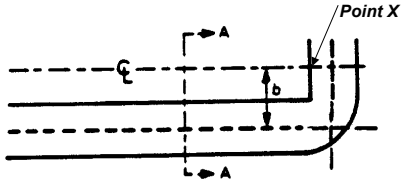
Find: *The pressure increase (ΔP) under the proposed abutment centerline (point X) at a depth of 64 ft (0.8b) below the base of the fill.*



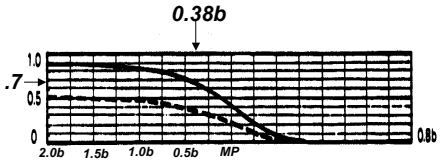
Slide 6-1-26

SOILS AND FOUNDATIONS WORKSHOP

USE OF PRESSURE DISTRIBUTION CHART EXAMPLE SOLUTION



Solution: Distance from midpoint of end slope to point 'X' = 30' so enter chart at 30/80b = 0.38b



From 0.8b depth chart read K = 0.7

At 64' depth $\Delta P = K\gamma_F h = (0.7)(100\ pcf)(30\ ft)$

$\Delta P = 2100\ psf$

Slide 6-1-27

SOILS AND FOUNDATIONS WORKSHOP

Settlement - Cohesionless Soils

1. ***Determine "corrected" SPT (N') value from Figure 6.5.***
2. ***Determine "Bearing Capacity Index" (C') by entering Figure 6.6 with N' value.***
3. ***Compute settlement in 10' ± increments of depth from:***

$$\Delta H = H \frac{1}{C'} Log \frac{Po + \Delta P}{Po}$$

Where:

ΔH = Settlement

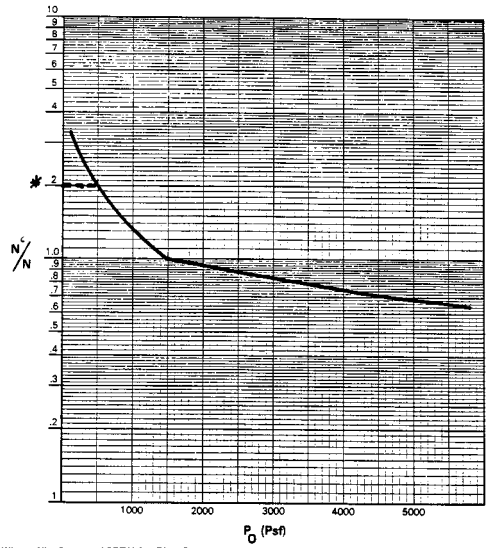
C' = Bearing capacity index

Po = Existing effective overburden pressure at center of layer

ΔP = Distributed embankment pressure at center of layer

Slide 6-1-28

SOILS AND FOUNDATIONS WORKSHOP

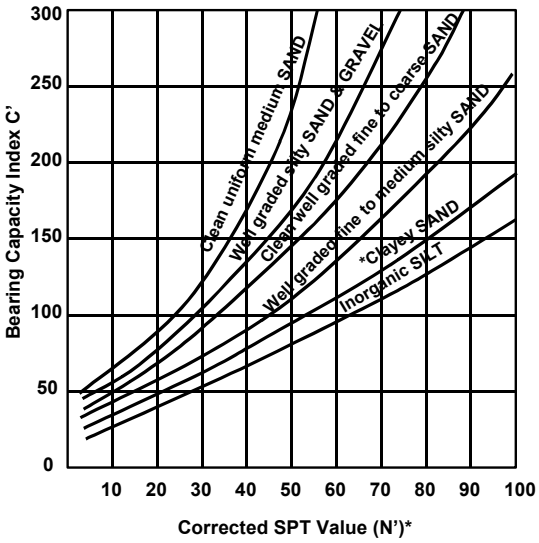


Where: N' = Corrected SPT Value Blow Count
N = SPT Value
P_O = Existing Effective Vertical Overburden Pressure
* = Suggested Maximum Value

Reference: Based on 1967, Bazaraa, The Use of Standard Penetration Test for Estimating Settlement of Shallow Foundation on Sand

Slide 6-1-29

SOILS AND FOUNDATIONS WORKSHOP

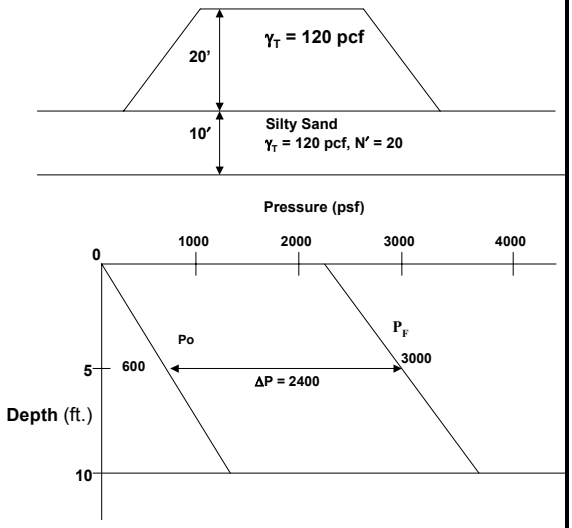


* Revised by Author from Sandy Clay in Original Hough Paper

Slide 6-1-30

SOILS AND FOUNDATIONS WORKSHOP

Example: Determine The Settlement Of The Embankment Due To Consolidation Of The Silty Sand Layer Using The P_O Diagram.



Slide 6-1-31

SOILS AND FOUNDATIONS WORKSHOP

Solution

Find C′: ***Use N′= 20 and Silty Sand Curve In Figure 6-6***
C′= 58

Find Settlement

$$\Delta H = H\frac{1}{C'}\,\text{Log}\,\frac{P_0 + \Delta P}{P_0}$$

$$\Delta H = 10'\left(\frac{1}{58}\right)\,\text{Log}\,\frac{600\text{ psf} + 2400\text{ psf}}{600\text{ psf}}$$

$$\Delta H = 0.12' = 1.44''$$

Slide 6-1-32

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

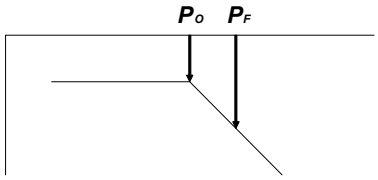
FIND: 1. N' (SPT value corrected for Po effect - Fig. 6-5)

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

Slide 6-1-33

SOILS AND FOUNDATIONS WORKSHOP

Settlement Estimate - N.C. Clay



$$\Delta H = H \frac{Cc}{1 + e_o} \text{ Log } \frac{P_F}{P_O}$$

H = Thickness of clay layer

Cc = Compression index (e-log P curve)

e_o = Initial void ratio of clay

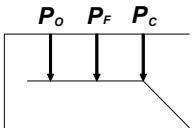
P_o = Existing effective overburden pressure (psf) @ center of layer

P_F = Final effective pressure (P_o + ΔP)

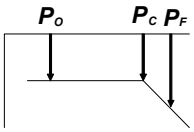
Slide 6-1-34

SOILS AND FOUNDATIONS WORKSHOP

Settlement Estimate - O.C. Clay



$$\Delta H = H \frac{Cr}{1 + e_o} \text{ Log } \frac{P_F}{P_O}$$



$$\Delta H = H \frac{Cr}{1 + e_o} \text{ Log } \frac{P_C}{P_O} + H \frac{Cc}{1 + e_o} \text{ Log } \frac{P_F}{P_C}$$

H = Thickness of clay layer

Cc = Compression index (e-log P curve)

Cr = Recompression index

e_o = Initial void ratio of clay

P_o = Existing effective overburden pressure (psf) @ center of layer

P_c = Preconsolidation pressure

P_F = Final effective pressure ($P_o + \Delta P$)

Slide 6-1-35

SOILS AND FOUNDATIONS WORKSHOP

Settlement Time

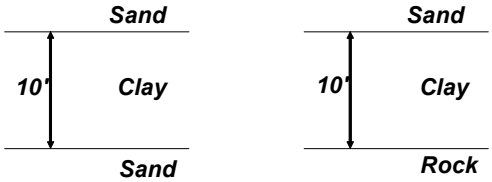
$$t = \frac{T H_v^2}{C_v}$$

t = Time for settlement (days)

T = Time factor

H_v = Vertical drainage path (ft)

C_v = Coefficient of consolidation (ft^2/day)

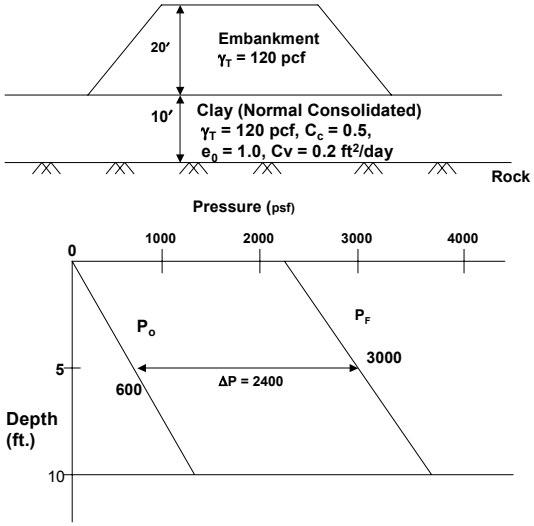


$H_v = 5'$ $H_v = 10'$

Slide 6-1-36

SOILS AND FOUNDATIONS WORKSHOP

Example: Determine The Magnitude And The Time For 90% Consolidation For The Primary Settlement Of The Embankment Using The P_o Diagram.



Slide 6-1-37

SOILS AND FOUNDATIONS WORKSHOP

Solution:

Find Primary Settlement

$$\Delta H = H\frac{C_c}{1+e_0}\,\text{Log}\frac{P_0+\Delta P}{P_0}$$

$$= 10'\left(\frac{0.5}{1+1.0}\right)\,\text{Log}\,\frac{600\text{ psf} + 2400\text{ psf}}{600\text{ psf}}$$

$$\Delta H = 1.75' = 21''$$

Find Time to 90% Consolidation: Assume Single Vertical Drainage Due to Impervious Rock Layer.

$$t_{90} = \frac{TH_V^2}{C_V}$$

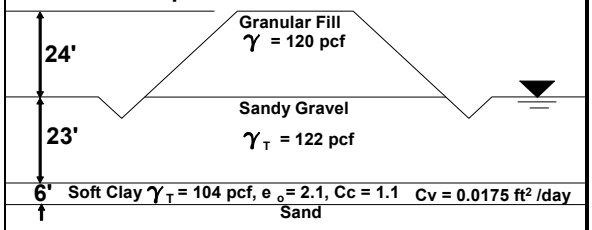
$$t_{90} = \frac{(0.848)(10)^2}{0.2} = 424\text{ days}$$

Slide 6-1-38

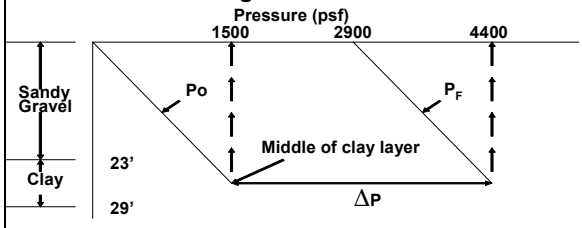
SOILS AND FOUNDATIONS WORKSHOP

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**

Slide 6-1-39

SOILS AND FOUNDATIONS WORKSHOP

Embankment Settlement

- ***Estimate compressibility from basic soils data***
- ***Calculate settlement***

Activities:

- ***Compressibility analysis***
- ***Settlement analysis***

Slide 6-1-40

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

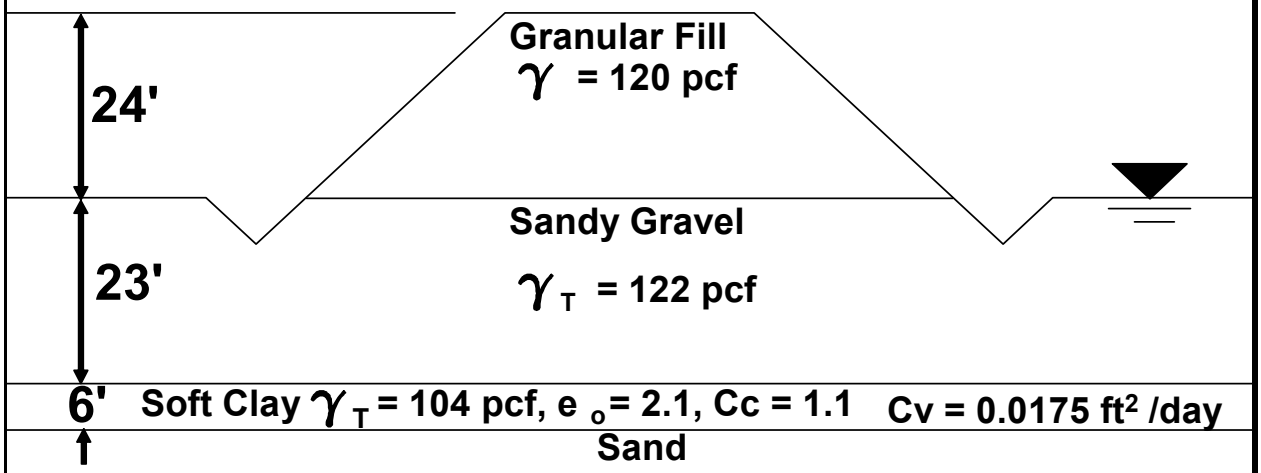
FIND: 1. N' (SPT value corrected for Po effect - Fig. 6-5)

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

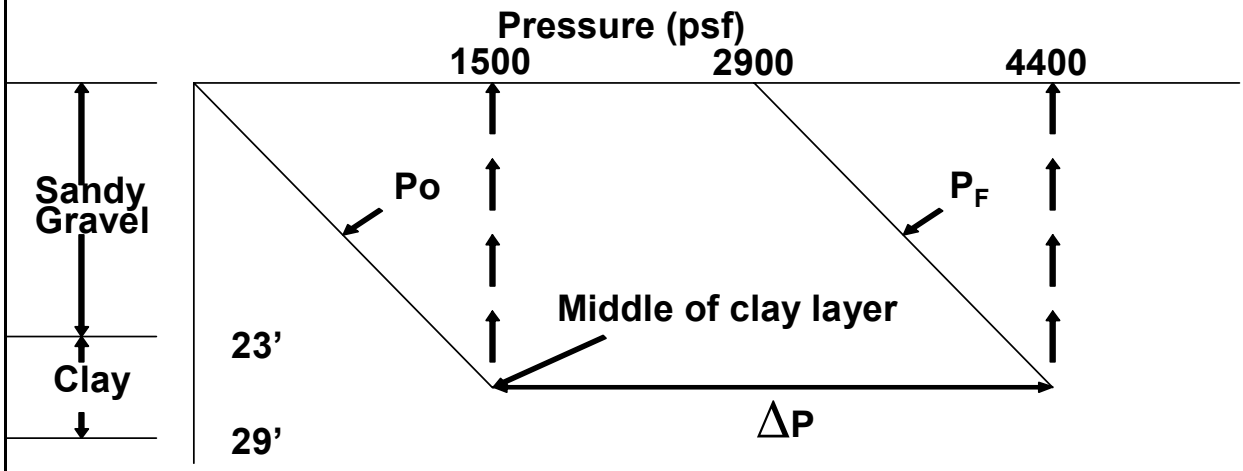
SOILS AND FOUNDATIONS WORKSHOP

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

LESSON 6

TOPIC 2

Treatment for Embankment Settlement Problems

TREATMENT FOR EMBANKMENT SETTLEMENT PROBLEMS

Lesson 6 - Topic 2

Slide 6-2-1

TREATMENT FOR EMBANKMENT SETTLEMENT PROBLEMS

1. Propose Solutions to Embankment Settlement Problems

ACTIVITIES: Question - Answer

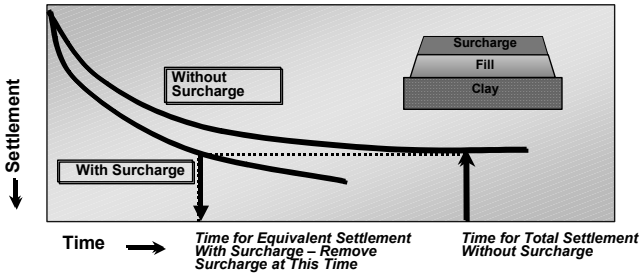
Slide 6-2-2

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

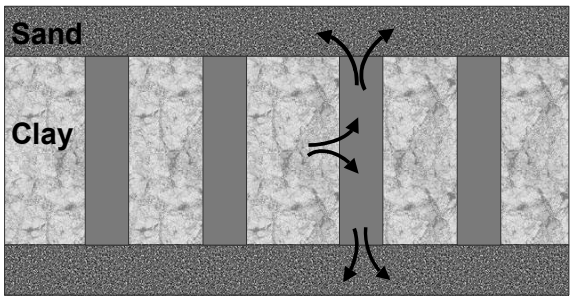
Embankment on Clay Foundation Effect of Surcharge Treatment



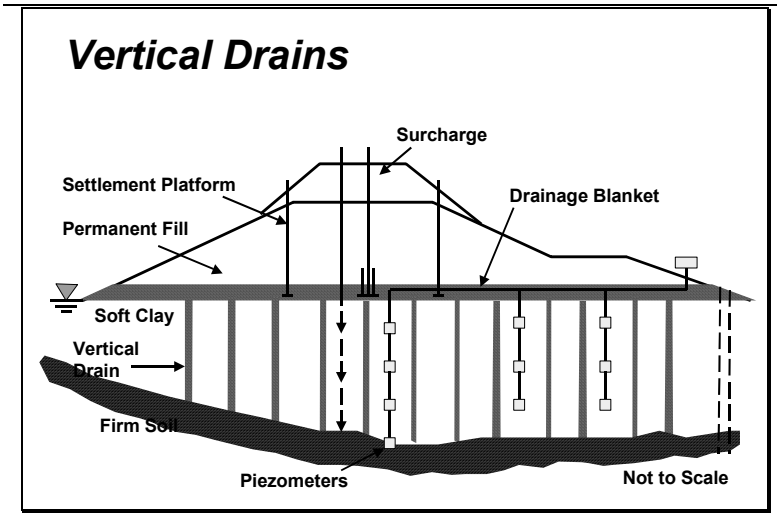
Slide 6-2-4

Slide 6-2-5

Acceleration of Consolidation Using Vertical Drainage



Slide 6-2-6



Slide 6-2-7

Slide 6-2-8

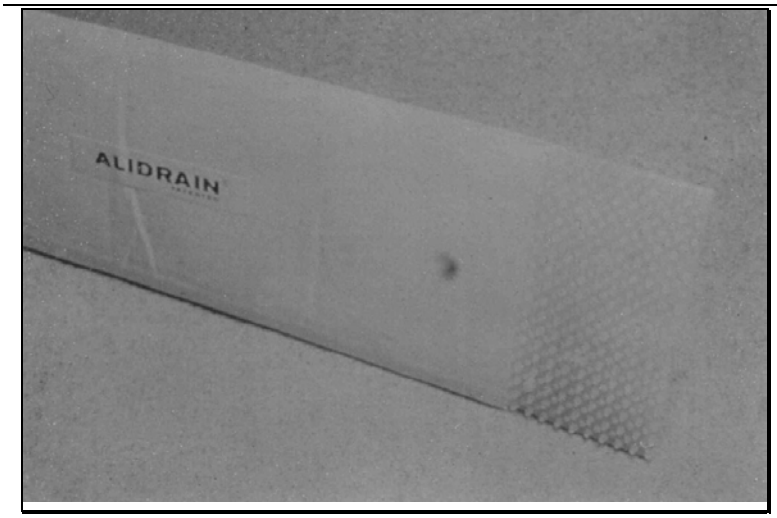
Slide 6-2-9

Vertical Drain Installation Sequence

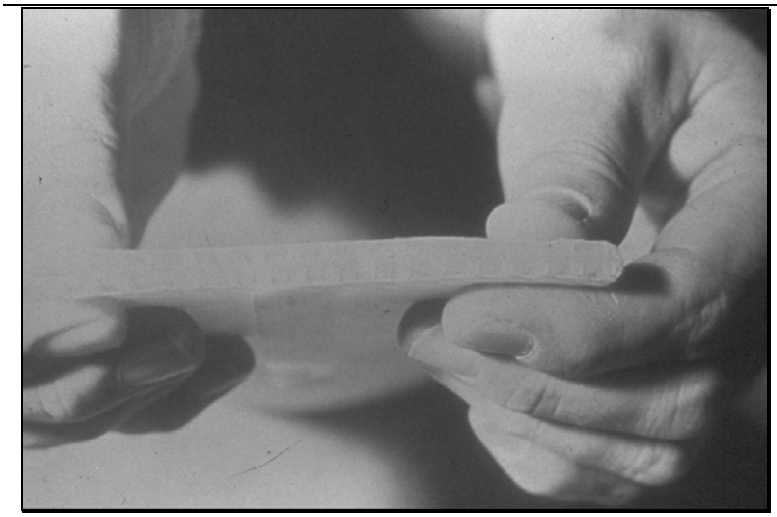
- ***Position Rig at Drain Location***
- ***Place Anchor on Drain End***
- ***Penetrate Mandrel to Desired Depth***
- ***Withdraw Mandrel***
- ***Cut Drain Material Above Drainage Blanket***

Slide 6-2-10

Slide 6-2-11



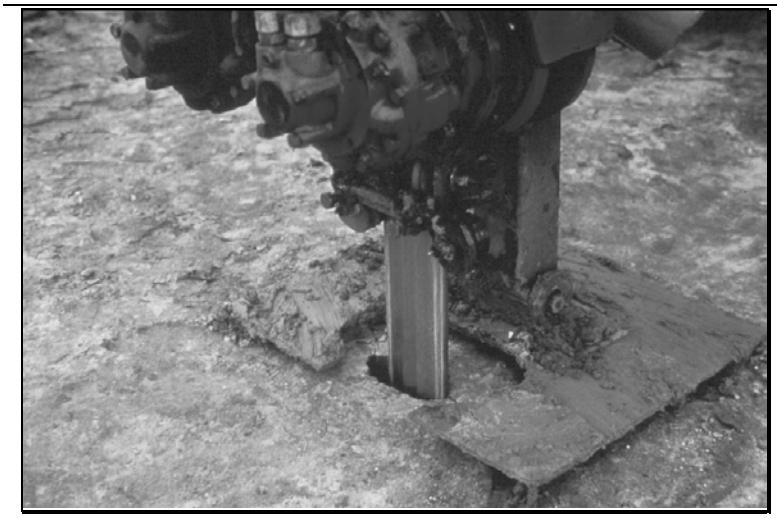
Slide 6-2-12



Slide 6-2-13

Slide 6-2-14

Slide 6-2-15



Slide 6-2-16

Slide 6-2-17

Slide 6-2-18

Slide 6-2-19

SOILS AND FOUNDATIONS WORKSHOP

Site Exploration

Basic Soil Properties

Laboratory Testing

Slope Stability

Embankment Settlement

Spread Footing Design

Pile Design

Construction Aspects

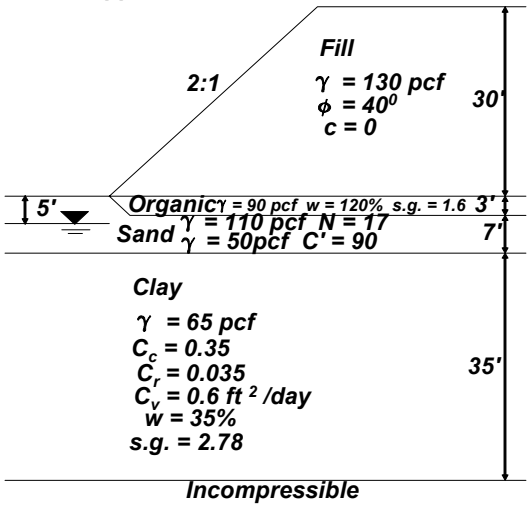
→

Soil Profile
Settlement
Time – Rate
Surcharge
Vertical Drains

Slide 6-2-20

SOILS AND FOUNDATIONS WORKSHOP

Apple Freeway Design Problem
East Approach Embankment Settlement

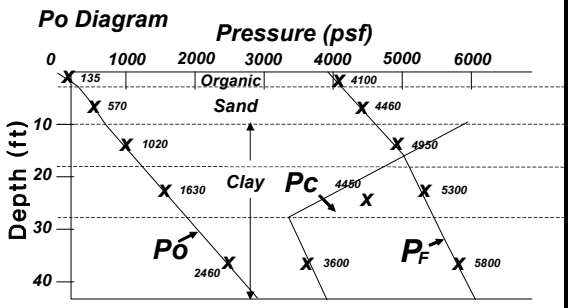


Slide 6-2-21

SOILS AND FOUNDATIONS WORKSHOP

Apple Freeway Design Problem

East Approach Embankment Settlement



Slide 6-2-22

SOILS AND FOUNDATIONS WORKSHOP

Apple Freeway Design Problem
East Approach Embankment Settlement

Total Settlement

Layer 1 - Organic (0' -3')	*19.54"*
Layer 2 - Sand (3' - 10')	*0.83"*
Layer 3 - Clay (10' - 18')	*1.17"*
Clay (18' - 28')	*2.55"*
Clay (28' - 45')	*8.11"*
ΔH_{Total}	*32.20"*

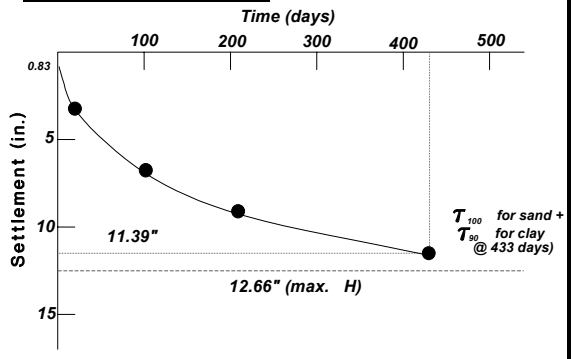
Slide 6-2-23

SOILS AND FOUNDATIONS WORKSHOP

Apple Freeway Design Problem

East Approach Embankment Settlement

Time - Settlement Plot



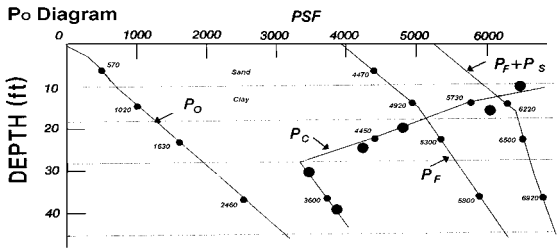
Slide 6-2-24

SOILS AND FOUNDATIONS WORKSHOP

Apple Freeway Design Problem

East Approach Embankment Surcharge

Assume:
10' high compacted surcharge (γ = 130 pcf)
Δ P of emb. (P_F) + surch. (P_S) = 5200 psf



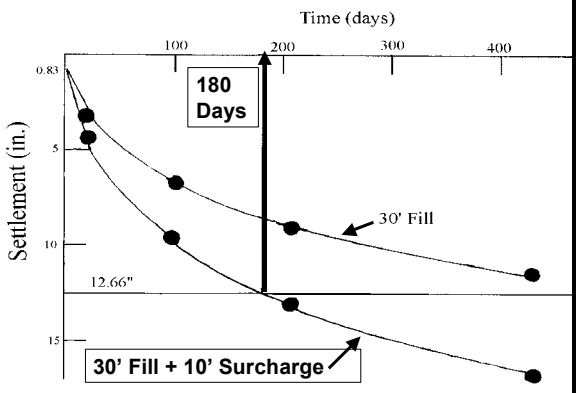
Slide 6-2-25

SOILS AND FOUNDATIONS WORKSHOP

Apple Freeway Design Problem

East Approach Embankment Surcharge

Time - Settlement Plot

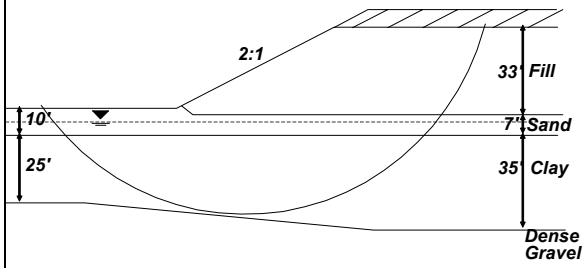


Slide 6-2-26

SOILS AND FOUNDATIONS WORKSHOP

WORKSHOP DESIGN PROBLEM
APPLE FREEWAY - E. APPROACH EMB.

Recheck stability of 30' Fill With 10' Surcharge
F.S.$_{Bishop}$= 1.33



F.S. w/surcharge = 1.33 (1.63 w/o surcharge)

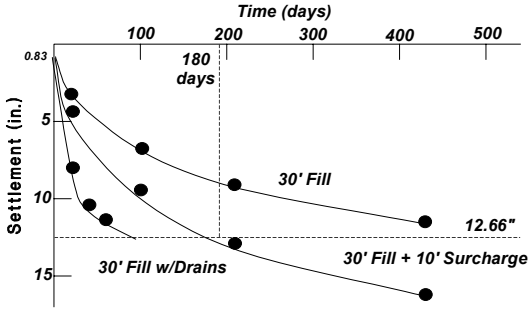
Slide 6-2-27

SOILS AND FOUNDATIONS WORKSHOP

Apple Freeway Design Problem

East Approach Embankment Settlement

Time - Settlement Plot



Treatment	***t_{90} (mo.)***	***Extra Cost***
Fill only	***14***	***-***
Fill w/10' surcharge	***6***	***$120,000***
fill w/ wick drain	***2***	***$172,000***
Fill w/sand drain	***2***	***$385,000***

Slide 6-2-28

SOILS AND FOUNDATIONS WORKSHOP

Apple Freeway Problem
East Approach Embankment Settlement

Lateral Squeeze of Clay

Remember: $\gamma_{Fill} \times H_{Fill} > 3 \times$ ***Cohesion***

3900 psf > 3300 psf

-> Can get lateral squeeze of clay

"Rule of Thumb"

Horizontal abutment movement:

= 0.25 x Fill Settlement

= (0.25)(11.8) = 3"

-> Recommend waiting period at abutment to remove settlement and prevent horizontal movement of abutments.

Slide 6-2-29

SOILS AND FOUNDATIONS WORKSHOP

Approach Embankment Settlement

Design Soil Profile

Soil layer consolidation properties selected

Settlement

32" settlement predicted
Recommend organic excavation
Rec. waiting period @ abut.

Time-Rate

433 days for t_{90}

Surcharge

10' surcharge improves t_{90} ***to 190 days***
Cost $120,000, F.S. = 1.33 O.K.

Vertical Drains

60 days for t_{90}
Cost $172,000 -> $385,000

Slide 6-2-30

SOILS AND FOUNDATIONS WORKSHOP

TREATMENT FOR EMBANKMENT SETTLEMENT PROBLEMS

1. Propose Solutions to Embankment Settlement Problems

ACTIVITIES: ***Question -Answer***

Slide 6-2-31

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

SPREAD FOOTING DESIGN

Lesson 7 - Topic 1
Bearing Capacity

Slide 7-1-2

SPREAD FOOTING DESIGN
Bearing Capacity

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

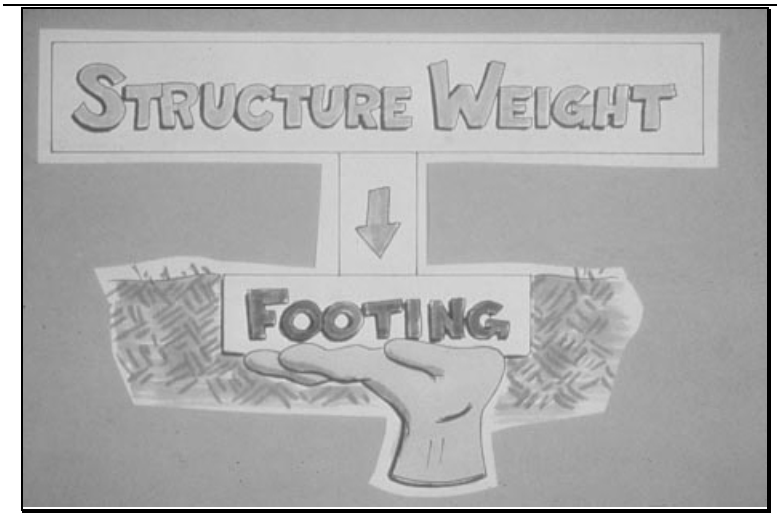
ACTIVITY: Bearing Capacity Analysis

Slide 7-1-3

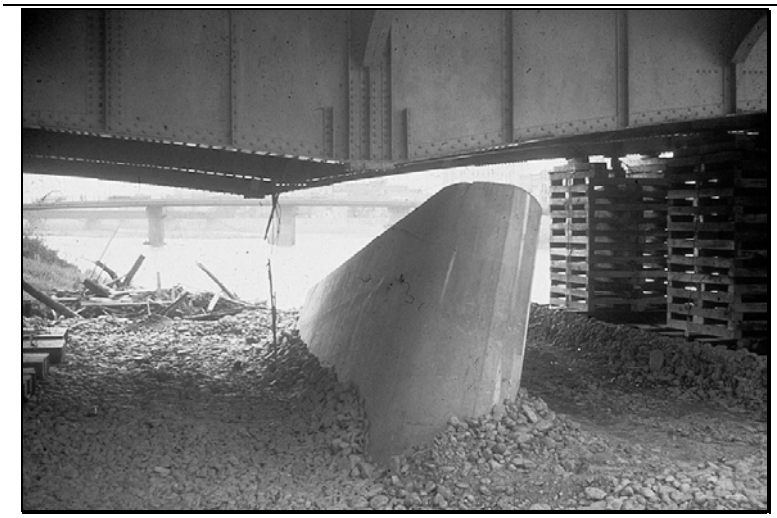
SOILS AND FOUNDATIONS WORKSHOP

What is the Effect on Bearing Capacity if the Soil Cover Over a Spread Footing is Removed?

Slide 7-1-4

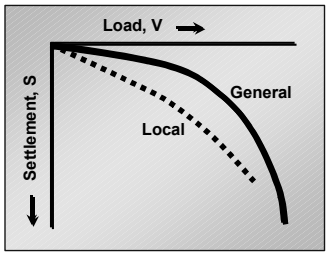


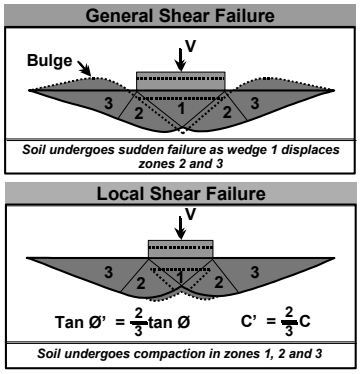
Slide 7-1-5



Slide 7-1-6

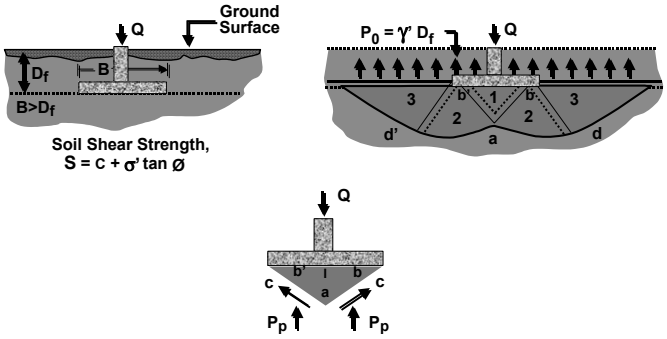
Failure Modes





Slide 7-1-7

Bearing Capacity Mechanism

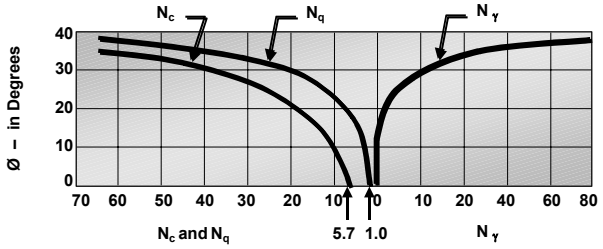


Slide 7-1-8

Bearing Capacity

Terzaghi Bearing Capacity Equation

$$q_u = cN_c + p_0N_q + \tfrac{1}{2}\gamma' BN_\gamma$$



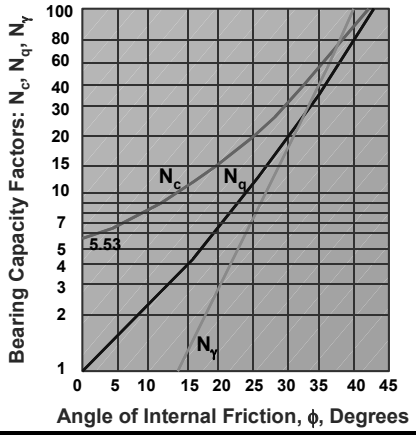
Slide 7-1-9

Bearing Capacity Equations

- ***Terzaghi:***
  - $q_{ult} = cN_c + P_oN_q + 1/2\gamma BN_\gamma$
- ***Brinch Hanson***
  - $q_{ult} = cN_c\, s_cd_ci_c + P_o\, N_qs_qd_qi_q + 1/2\gamma BN_\gamma s_\gamma d_\gamma i_\gamma$

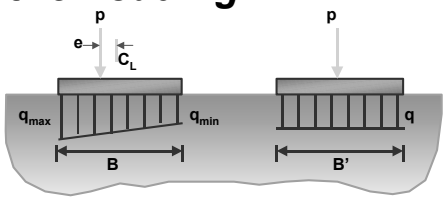
Slide 7-1-10

Bearing Capacity Factors

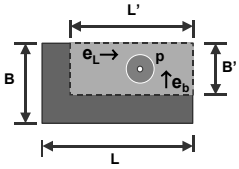


Slide 7-1-11

Eccentric Loading



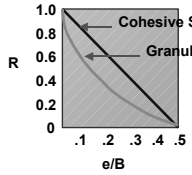
$B' = B - 2e$



$B' = B - 2e_b$

$L' = L - 2e_L$

Use B' and L' in place of B and L in Bearing Capacity Eq.

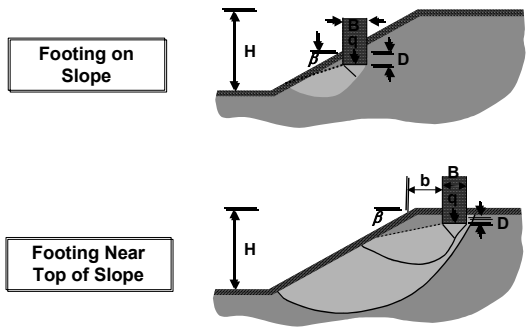


$q'_{ult} = Q_{ult}(R)$

Where R is a reduction factor for eccentric loading

Slide 7-1-12

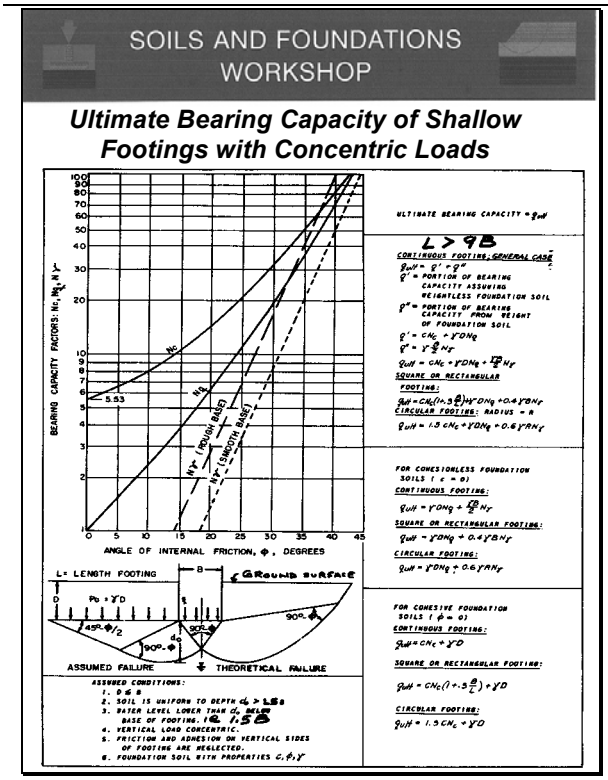
Bearing Capacity – Slope Effects



Slide 7-1-13

Slide 7-1-14

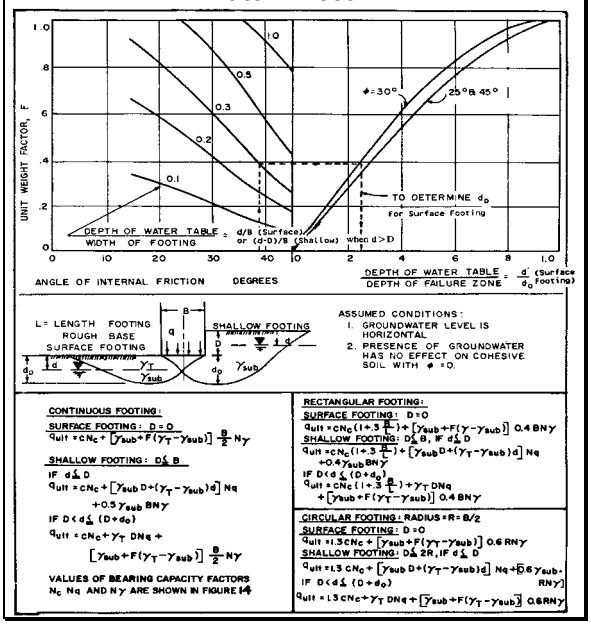
Slide 7-1-15



Slide 7-1-16

SOILS AND FOUNDATIONS WORKSHOP

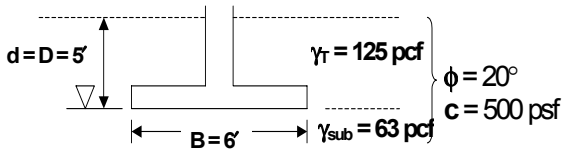
Ultimate Bearing Capacity with Ground Water Effect



Slide 7-1-17

SOILS AND FOUNDATIONS WORKSHOP

Example: Determine the Allowable Bearing Capacity for A Rough Base Square Footing Using A Safety Factor Of 3.



Slide 7-1-18

SOILS AND FOUNDATIONS WORKSHOP

Solution: Assuming A General Shear Condition, Enter the Bearing Capacity Chart for $\phi = 20^\circ$ and Read $N_c = 14$, $N_q = 6$, $N_\gamma = 3$. Also note that formula for bearing capacity must account for the square footing and the water table within the failure zone.

$$q_{ult} = (1 + 0.3\frac{B}{L})CN_c + [\gamma'_{sub}D + (\gamma_T - \gamma_{sub})d]N_q + 0.4\gamma'_{sub}BN\gamma$$

$$= (1.3)(500)14 + [63(5) + (125 - 63)5]6 + 0.4(63)(6)(3)$$

$$= 9100 + 3750 + 450$$

$$q_{ult} = 13{,}300\text{psf}$$

$$q_{all} = \frac{q_{ult}}{3} = \frac{13{,}300}{3} \cong 4{,}430\text{psf}$$

Slide 7-1-19

SOILS AND FOUNDATIONS WORKSHOP

What is the Effect on Bearing Capacity of Excavation of Soil Cover Over a Spread Footing?

Slide 7-1-20

SOILS AND FOUNDATIONS WORKSHOP

Student Mini-Exercise on Bearing Capacity

$$q_{ult} = cN_c + P_oNq + 1/2\gamma BN_\gamma$$

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'		

Slide 7-1-21

SOILS AND FOUNDATIONS WORKSHOP

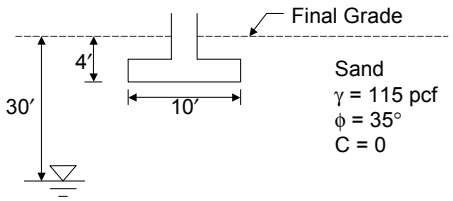
STUDENT EXERCISE NO.5

Footing Bearing Capacity

Objective:

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

Rough Base Footing 10′ × 50′

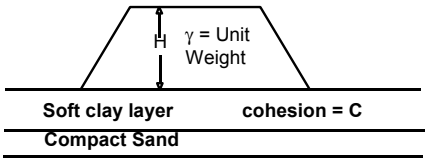


Slide 7-1-22

SOILS AND FOUNDATIONS WORKSHOP

How is bearing capacity theory related to the "rule of thumb" equation for stability;

$$\textit{SAFETY FACTOR} = \frac{6C}{\gamma H}$$



Slide 7-1-23

SOILS AND FOUNDATIONS WORKSHOP

Spread Footing Design Bearing Capacity

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

Activities: Bearing capacity analysis

Slide 7-1-24

SOILS AND FOUNDATIONS WORKSHOP

Student Mini-Exercise on Bearing Capacity

$$q_{ult} = cN_c + P_oNq + 1/2\gamma BN_\gamma$$

Properties and Dimensions ***(Assume Continuous Rough Footing)***	***Cohesive Soil***	***Cohesionless Soil***
γ = Unit Weight **D = Footing Embedment** **B = Footing Width**	**ϕ = 0°** **c = 1000psf**	**ϕ = 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

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

Properties and Dimensions ***(Assume Continuous Rough Footing)***	***Cohesive Soil***	***Cohesionless Soil***
γ = Unit Weight **D = Footing Embedment** **B = Footing Width**	**ϕ = 0°** **c = 1000psf**	**ϕ = 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

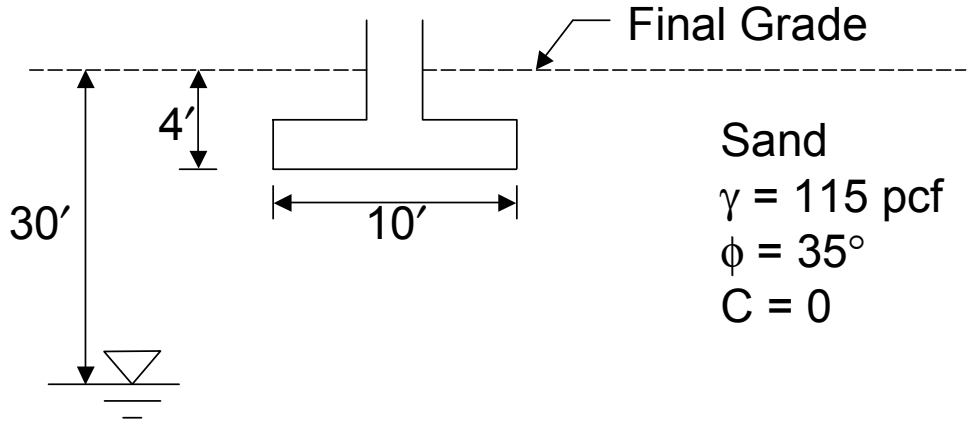
STUDENT EXERCISE NO.5

Footing Bearing Capacity

Objective:

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

Rough Base Footing 10′ × 50′



LESSON 7

TOPIC 2

Spread Footing Design - Settlement

SPREAD FOOTING DESIGN

Lesson 7 - Topic 2
Settlement

Slide 7-2-1

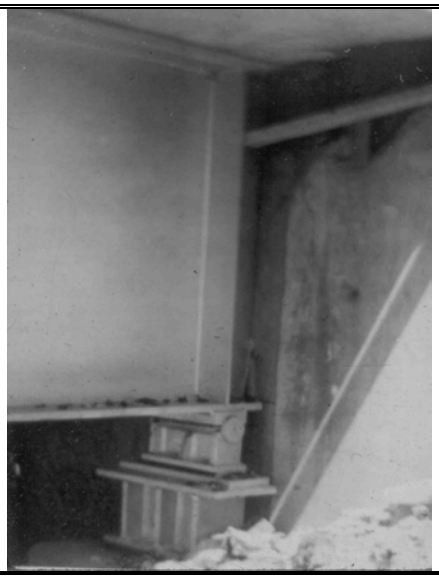
SPREAD FOOTING DESIGN Settlement

1. Perform Settlement Analysis in Cohesive and Granular Soil

2. Name Solutions to Reduce Settlement Amount or Time

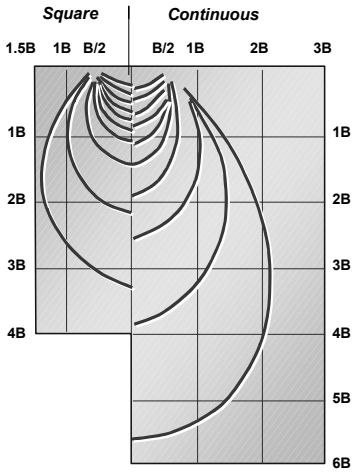
ACTIVITY: Settlement Analysis

Slide 7-2-2



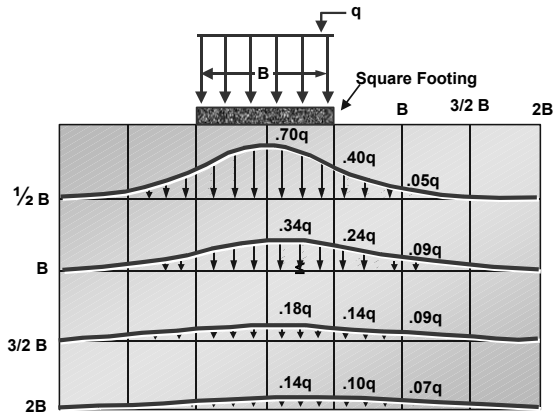
Slide 7-2-3

Boussinesq Pressure Isobars



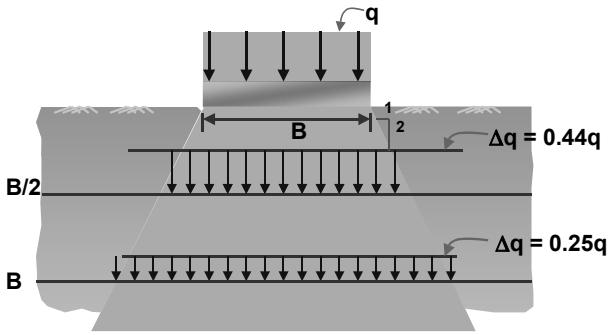
Slide 7-2-4

Boussinesq Pressure Distribution



Slide 7-2-5

2:1 Pressure Distribution

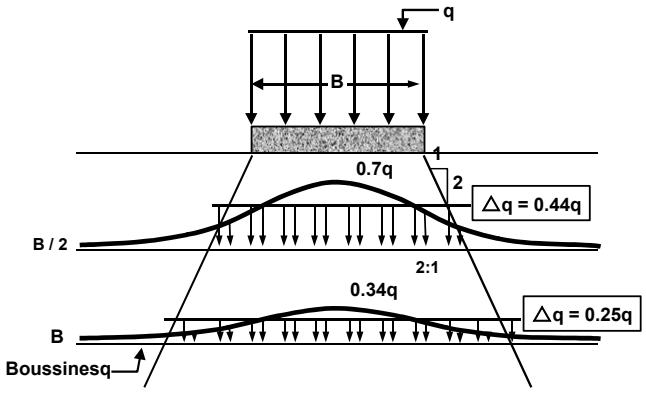


$$\Delta P = \frac{P}{(B+Z)^2}$$ (Square Footing)

$$\Delta P = \frac{P}{(B+Z)(L+Z)}$$ (Rectangular Footing)

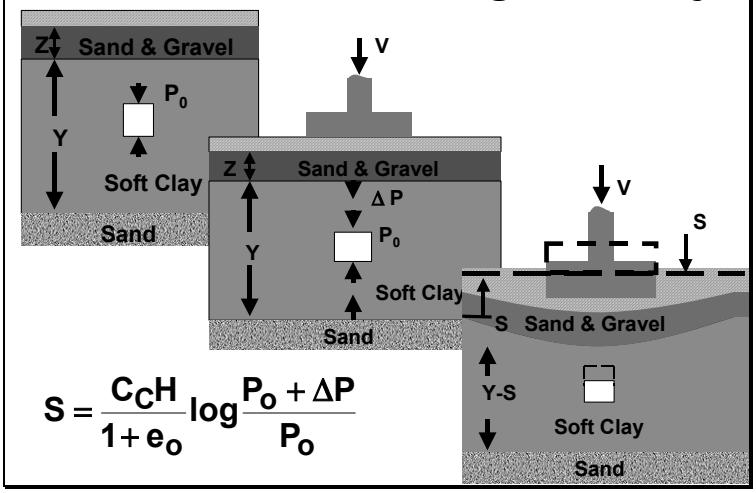
Slide 7-2-6

Comparison of 2:1 and Boussinesq Distribution



Slide 7-2-7

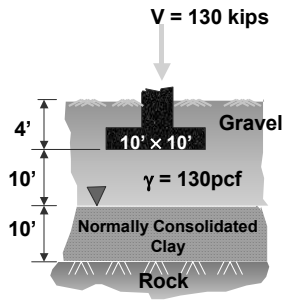
Settlement of Footings on Clay



$$S = \frac{C_C H}{1 + e_o} \log \frac{P_o + \Delta P}{P_o}$$

Slide 7-2-8

Example: Determine the Settlement of the Footing



γ' = 65 pcf

e_O = 0.75

C_C = 0.40

- *Overburden Pressure at Mid-Height of Clay Deposit:*

$$P_O = (14' \times 130\,pcf) + (5' \times 65\,pcf)$$
$$P_O = 2145\,psf$$

- *Change in Pressure at Mid-Height of Clay Deposit, using 2:1 Method*

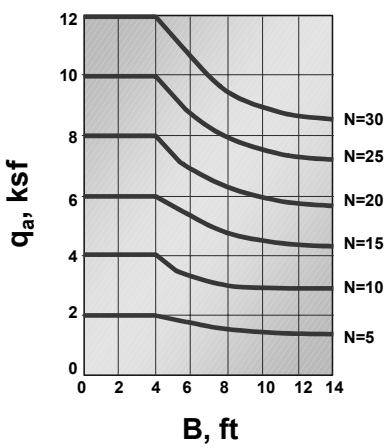
$$\Delta P = \frac{V}{(10+15)^2} = \frac{130{,}000\#}{625\,ft^2} = 208\,psf$$

$$\text{Settlement}: S = \frac{C_C H}{1+e_o} \log \frac{P_O + \Delta P}{P_O}$$

$$S = \frac{(0.40)(10')}{1+0.75} \log \frac{2145+208}{2145} = 0.09' = 1.1\,ins$$

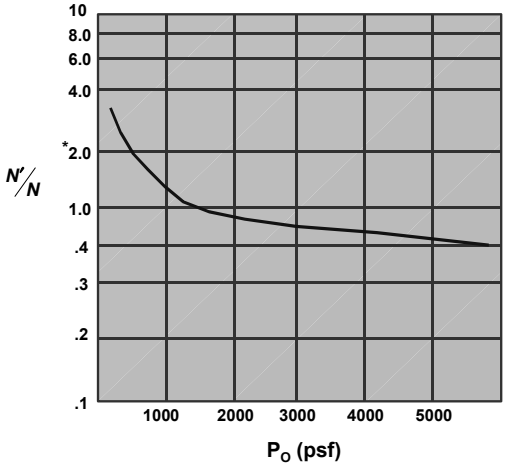
Slide 7-2-9

Settlement of Granular Soil



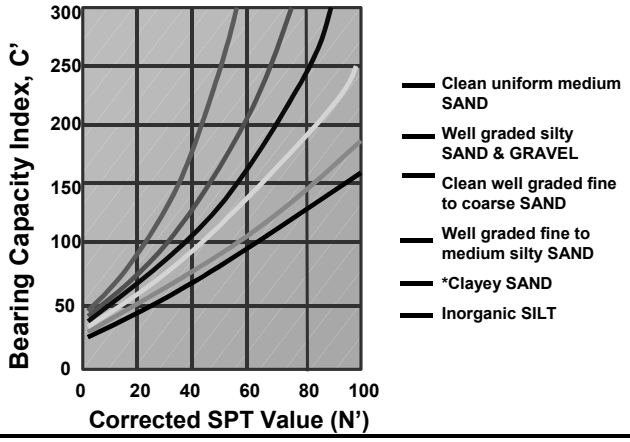
Slide 7-2-10

Correction SPT (N) Blow Counts



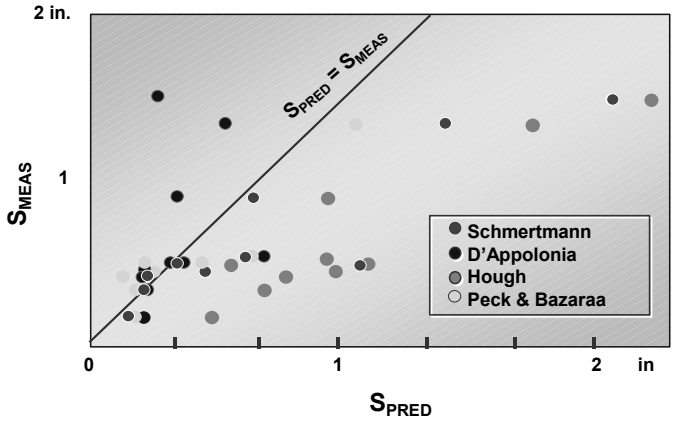
Slide 7-2-11

Bearing Capacity Index (C') Values for Granular Soils



Slide 7-2-12

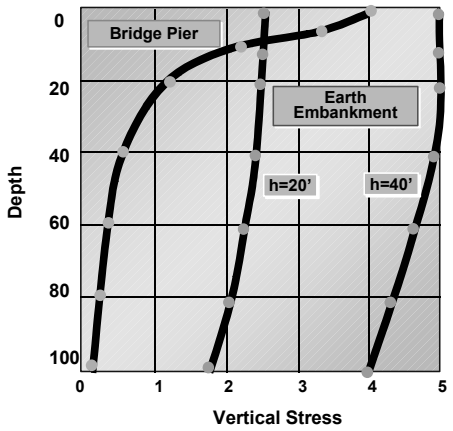
Case Histories of Settlement of Spread Footings



Slide 7-2-13

Slide 7-2-14

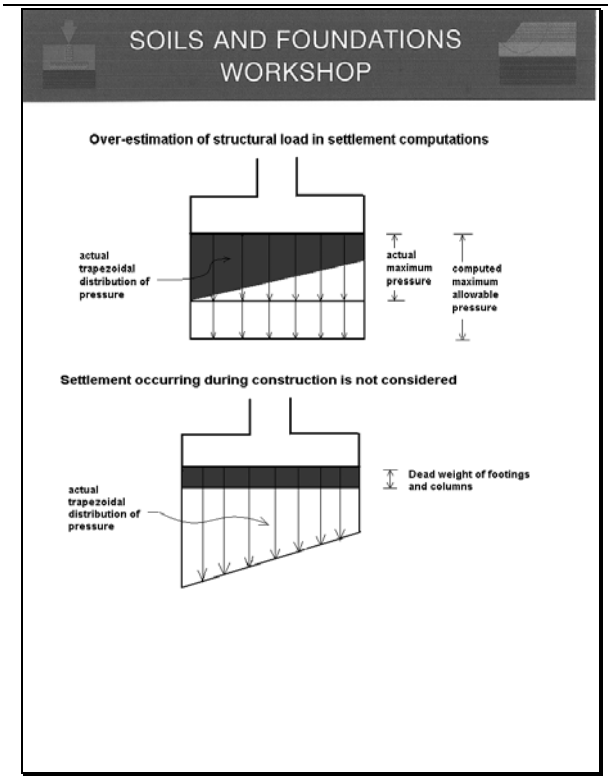
Vertical Stress Distribution



Slide 7-2-15

Slide 7-2-16

Slide 7-2-17



Slide 7-2-18

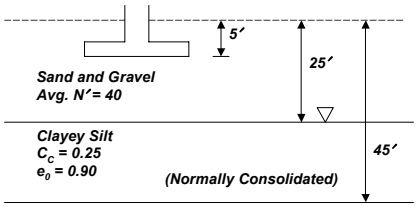
SOILS AND FOUNDATIONS WORKSHOP

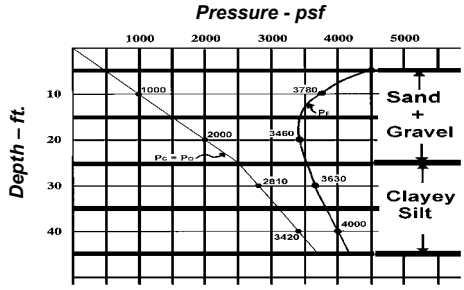
STUDENT EXERCISE NO. 6

Footing Settlement

Given: ***Soil Profile and Pressure Diagram Below***

Find Footing Settlement Using Increments of 10'





Slide 7-2-19

SOILS AND FOUNDATIONS WORKSHOP

Site Exploration

Basic Soil Properties

Laboratory Testing

Slope Stability

Embankment Settlement

Spread Footing Design

Design Soil Profile
Pier Bearing Capacity
Pier Settlement
Abutment Settlement
Vertical Drains
Surcharge

Pile Design

Slide 7-2-20

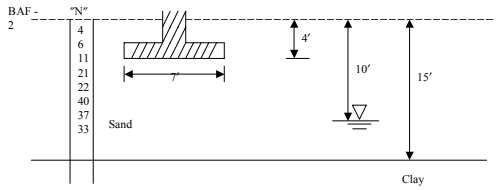
SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY

PIER BEARING CAPACITY

Assumptions:

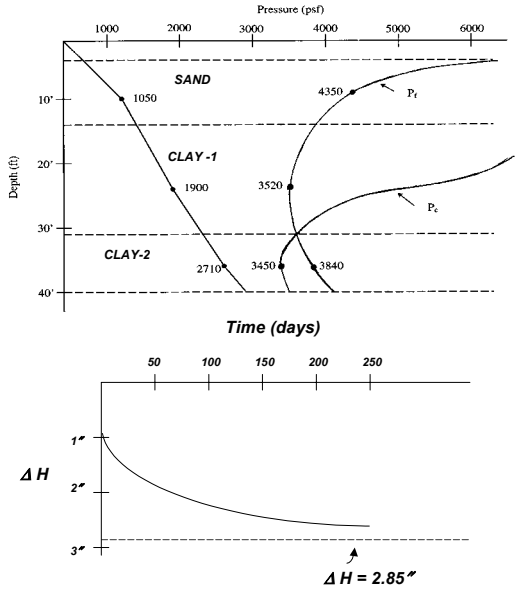
- ***Footing embeded 4′ below ground***
- ***Footing width = 1/3 pier height = 7′***
- ***Footing length = 100′***
  L/W = 100/7 > 9 ∴ Continuous



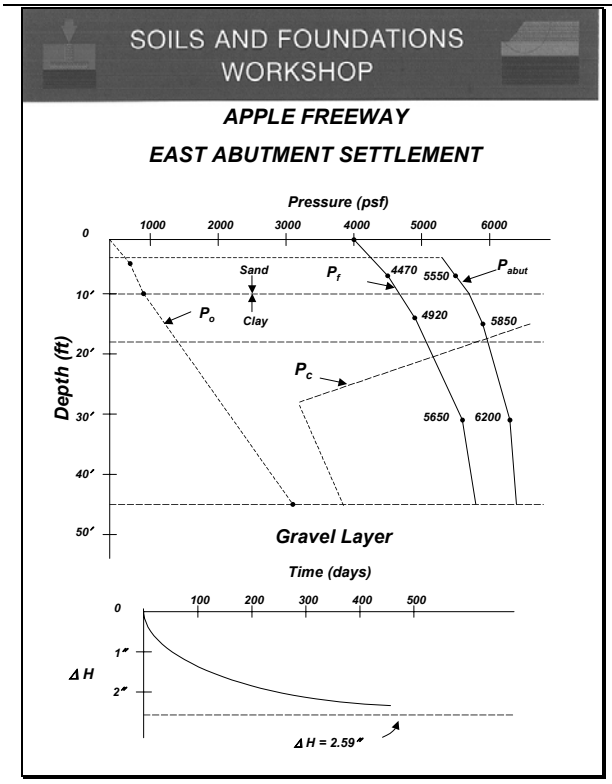
Slide 7-2-21

SOILS AND FOUNDATIONS WORKSHOP

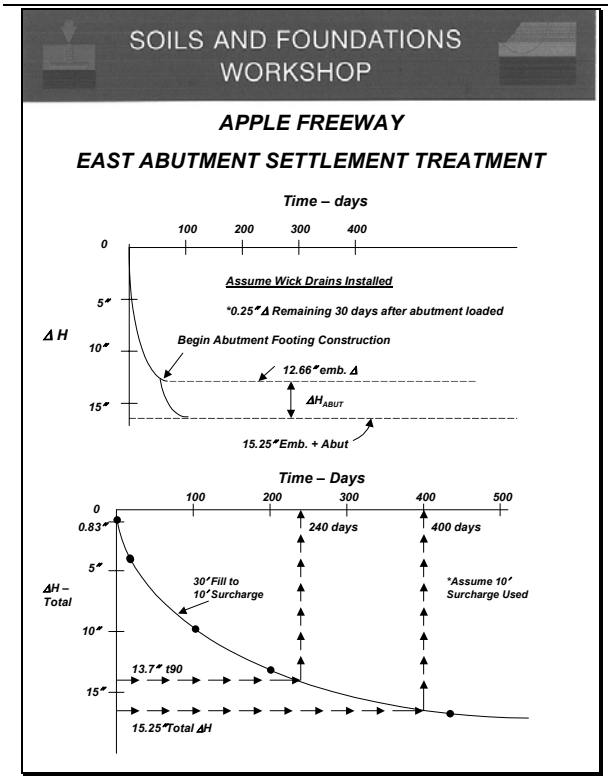
APPLE FREEWAY PIER SETTLEMENT



Slide 7-2-22



Slide 7-2-23



Slide 7-2-24

SOILS AND FOUNDATIONS WORKSHOP

SPREAD FOOTING DESIGN

Design Soil Profile

Strength and consolidation values selected for all soil layers. Footing elevation and width chosen.

Pier Bearing Capacity

$Q_{allowable}$ *= 3 tons/sq.ft.*

Pier Settlement

Settlement = 2.8", t_{90} = 220 days.

Abutment Settlement

Settlement - 2.6", t_{90} = 433 days.

Vertical Drains

t_{90} = 60 days - could reduce settlement to 0.25" after abutment constructed and loaded.

Surcharge

10' surcharge: t_{90} = 240 days before abutment constructed.

Slide 7-2-25

SOILS AND FOUNDATIONS WORKSHOP

Spread Footing Design Settlement

- ***Perform settlement analyses in both cohesive and granular soils***
- ***Name solutions to reduce settlement***

Activities: Settlement analysis

Slide 7-2-26

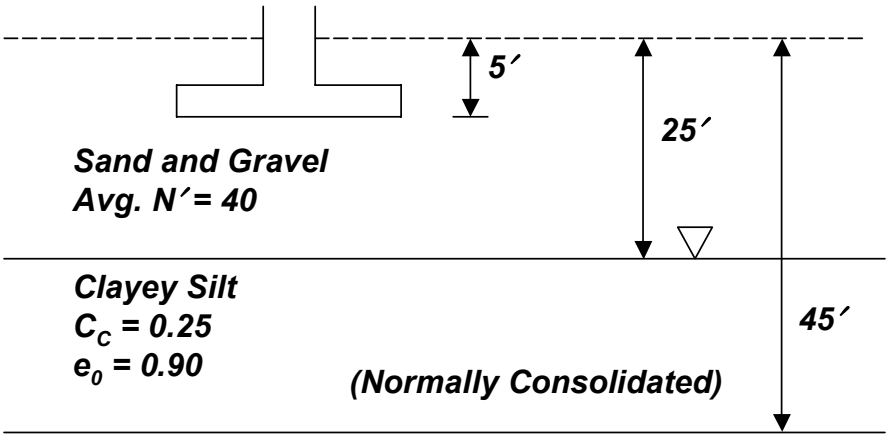
SOILS AND FOUNDATIONS WORKSHOP

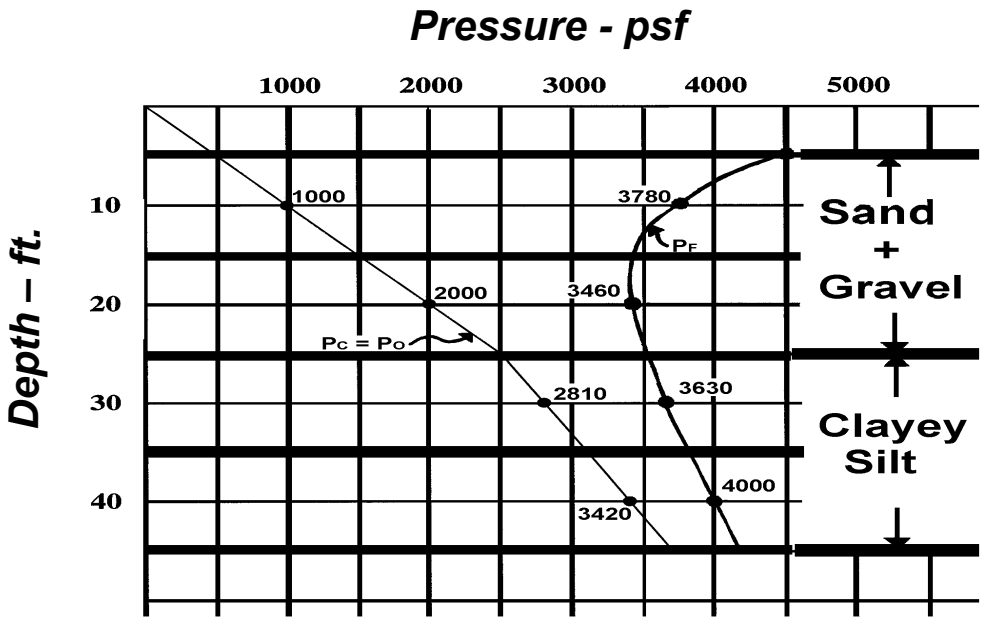
STUDENT EXERCISE NO. 6

Footing Settlement

Given: ***Soil Profile and Pressure Diagram Below***

Find Footing Settlement Using Increments of 10'





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

DEEP FOUNDATION DESIGN

Lesson 8 - Topic 1
Load Capacity

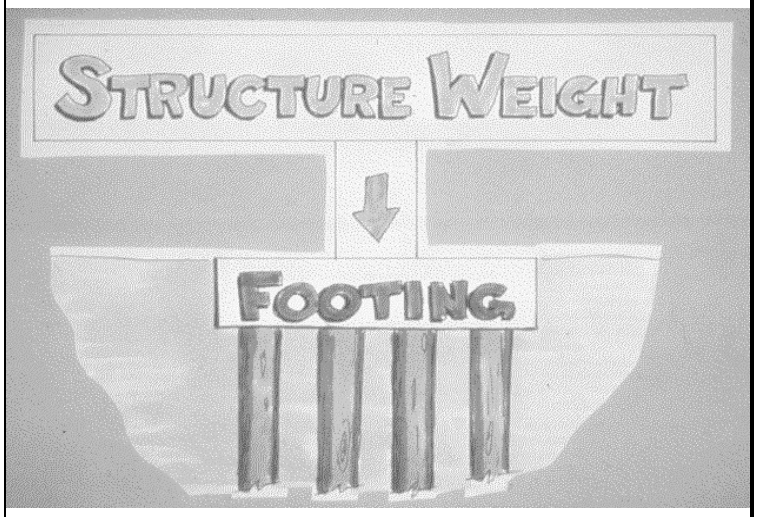
Slide 8-1-2

DEEP FOUNDATION DESIGN
Load Capacity

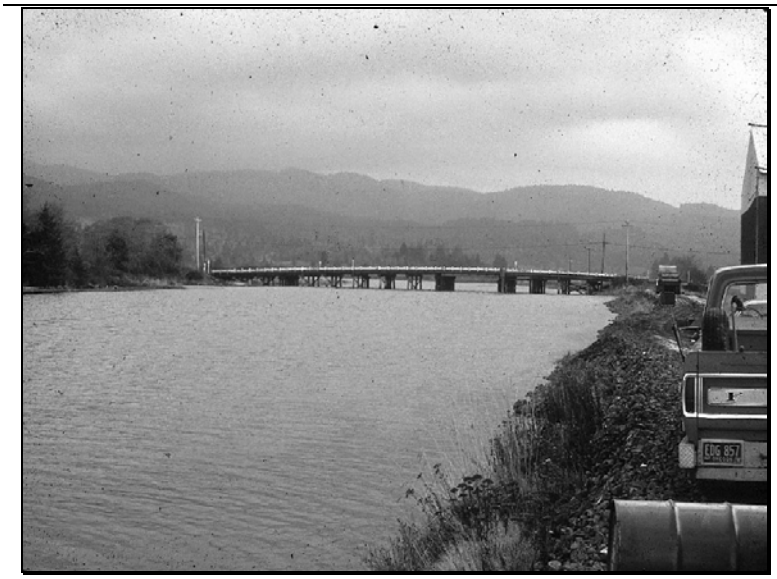
1. Describe Properties of the Pile and the Ground Which Affect Bearing Capacity

ACTIVITY: ***Static Analysis & Interpretation***

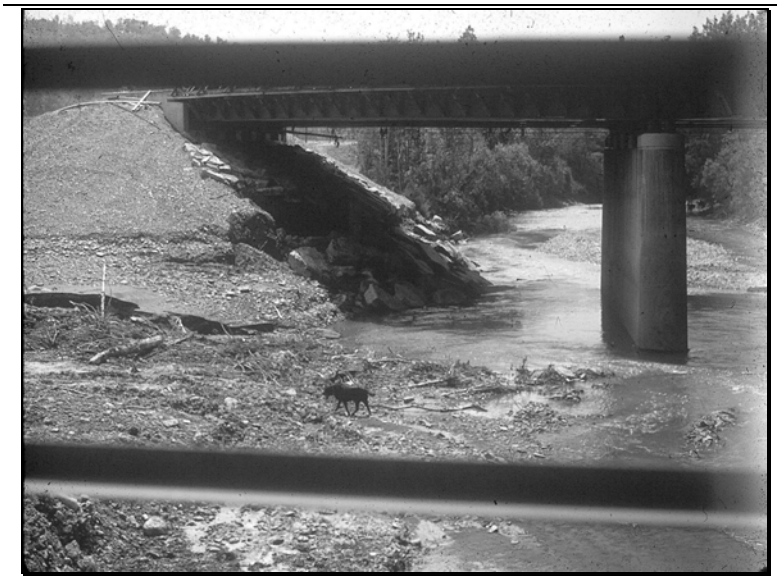
Slide 8-1-3



Slide 8-1-4

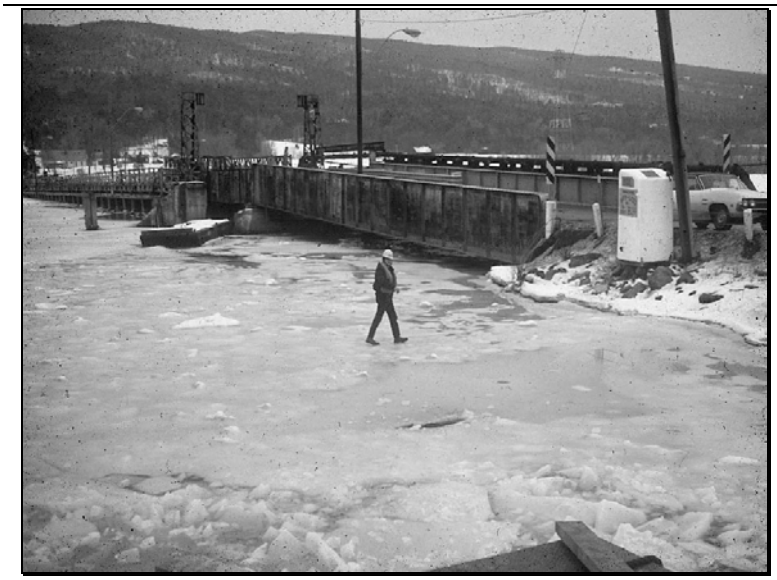


Slide 8-1-5

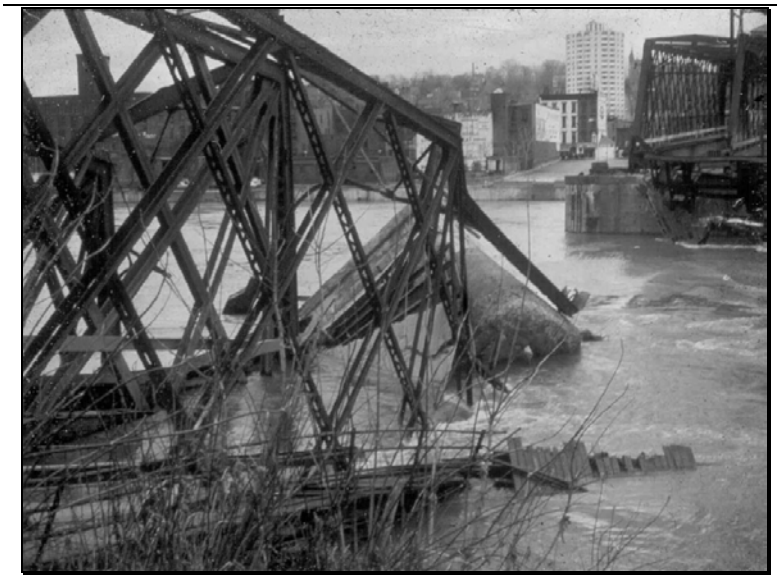


Slide 8-1-6

Slide 8-1-7

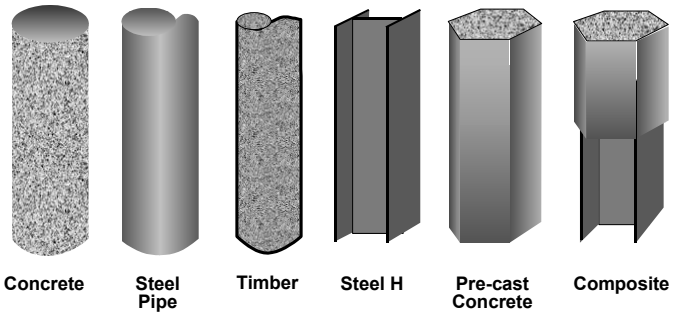


Slide 8-1-8



Slide 8-1-9

Types of Piling



Slide 8-1-10

Individual Piles

Method of Estimating Load Capacity

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

Slide 8-1-11

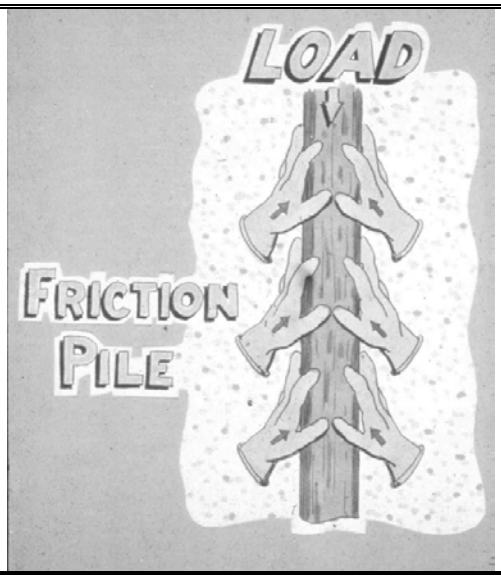
Slide 8-1-12

Slide 8-1-13

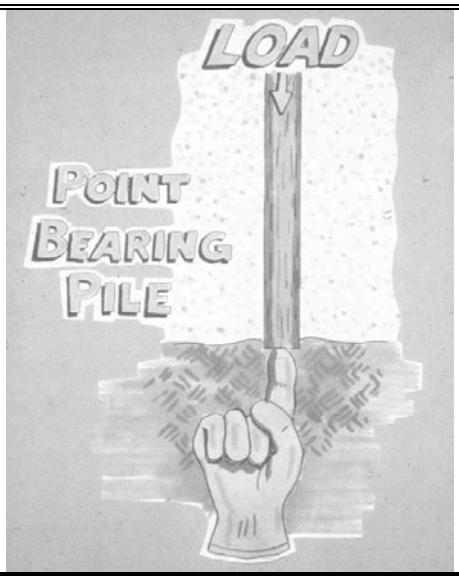
Steps in Rational Pile Selection

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

Slide 8-1-14

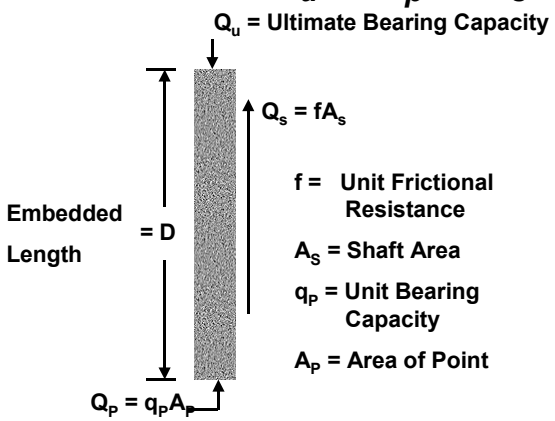


Slide 8-1-15



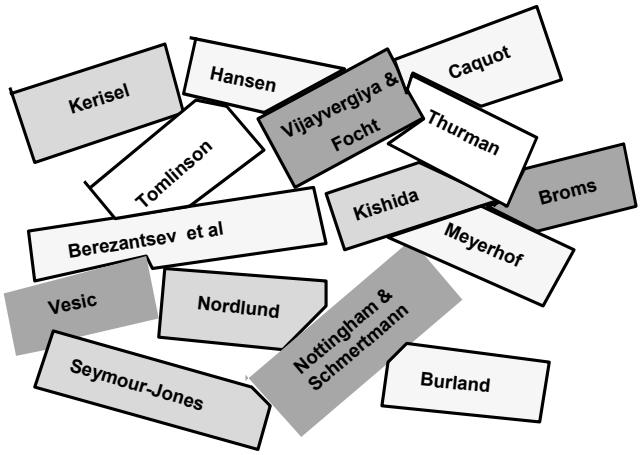
Slide 8-1-16

Ultimate Bearing Capacity - Static Formula Method ($Q_u = Q_p + Q_s$)



Slide 8-1-17

Static Pile Capacity



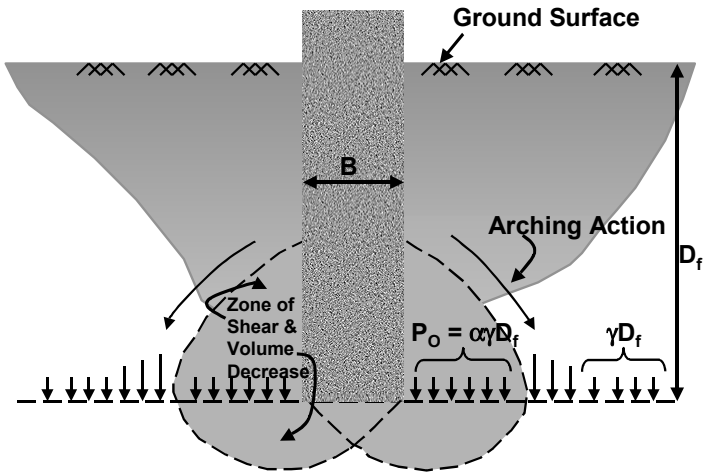
Slide 8-1-18

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***

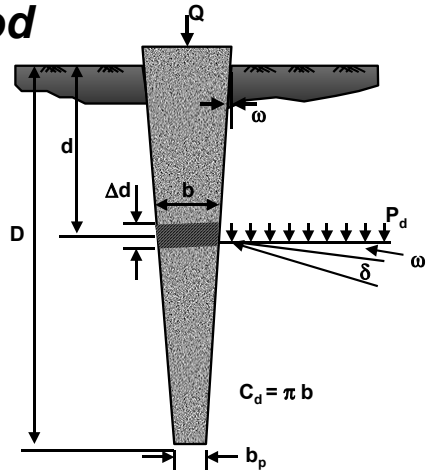
Slide 8-1-19

Arching at Pile Tip



Slide 8-1-20

Nordlund's Static Pile Capacity Method



Slide 8-1-21

Ultimate Capacity of Non-Tapered Piles in Granular Soils

$Q_u = Q_S + Q_P$

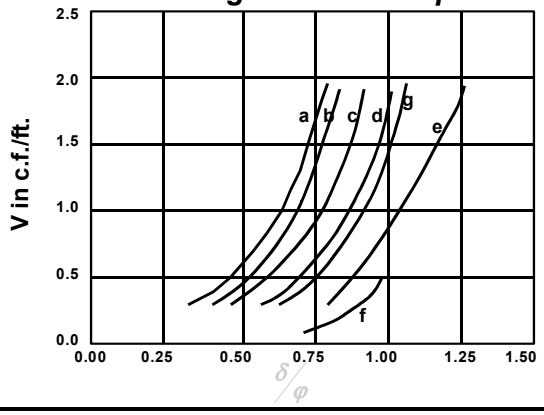
$Q_u = K_\delta C_F P_d \sin\delta \; C_d D + A_P \alpha P_D N'_q$

Unknowns are K_δ, C_F, δ, α, N'_q

Slide 8-1-22

Skin Friction in Granular Soils

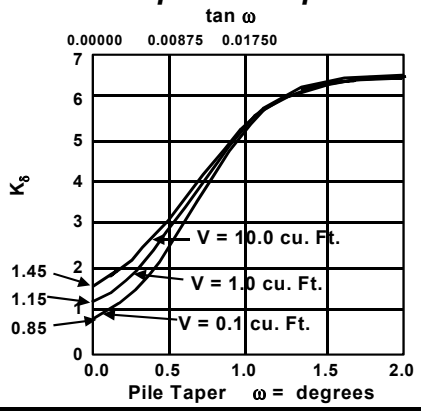
- *Effects of Roughness & Displacement*



Slide 8-1-23

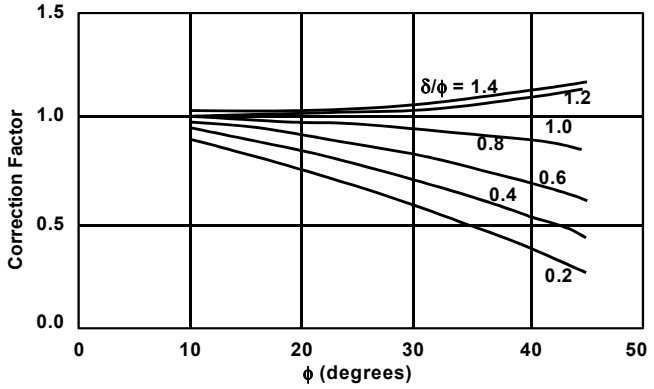
Skin Friction in Granular Soils

- *Effects of Taper & Displacement*



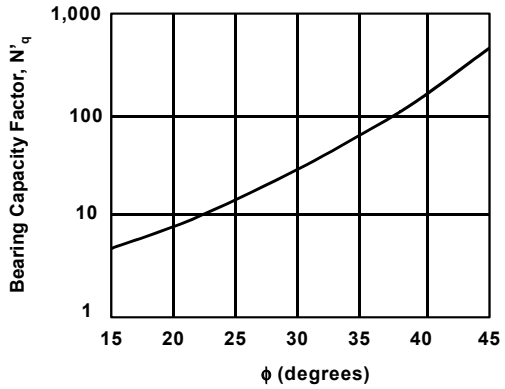
Slide 8-1-24

Skin Friction in Granular Soils Correction Factor if $\delta \neq \phi$



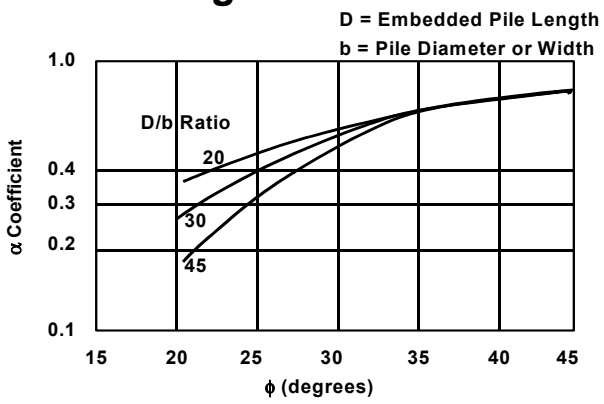
Slide 8-1-25

End Bearing in Granular Soils Bearing Capacity Factor - N'_q



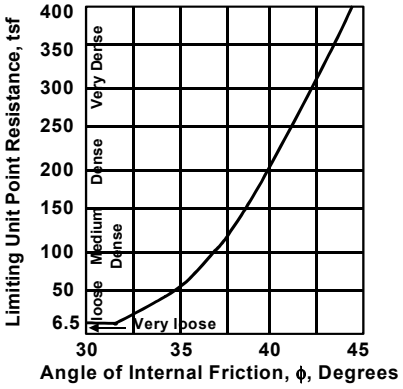
Slide 8-1-26

End Bearing in Granular Soils
Soil Arching Effects - α



Slide 8-1-27

End Bearing in Granular Soils
Limiting (Maximum) Value



Slide 8-1-28

Slide 8-1-29

Slide 8-1-30

Slide 8-1-31

SOILS AND FOUNDATIONS WORKSHOP

Static Analysis Equation (Granular Soil)

$$Q_s = K_\delta C_F P_d \ \sin\delta \ C_d D$$

(Normal Force) (Tangent φ) (Pile Surface Area)

$$Q_p = A_p \ \alpha P_D \ N'_q$$

(Point Area) (Reduced P_O) (Bearing Capacity Factor)

Slide 8-1-32

SOILS AND FOUNDATIONS WORKSHOP

Skin Friction Computations

- ***Compute volume per unit length***
- ***Enter Figure 8-1 with volume and pile type to find δ/ϕ. Then compute δ (interface friction angle)***
- ***Enter Figures 8-2 to 8-5 to find the lateral earth pressure coefficient, K_δ for the given value of ϕ and unit volume***

Slide 8-1-33

SOILS AND FOUNDATIONS WORKSHOP

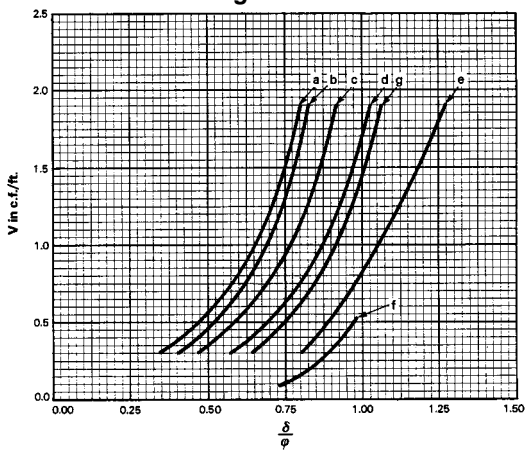
Skin Friction Computation (Cont'd)

- ***Enter Figure 8-6 with ϕ and the value of δ/ϕ to find the correction factor C_F for K_δ***
- ***Use P_o average and pile geometry to compute skin friction***

Slide 8-1-34

SOILS AND FOUNDATIONS WORKSHOP

Figure 8-1

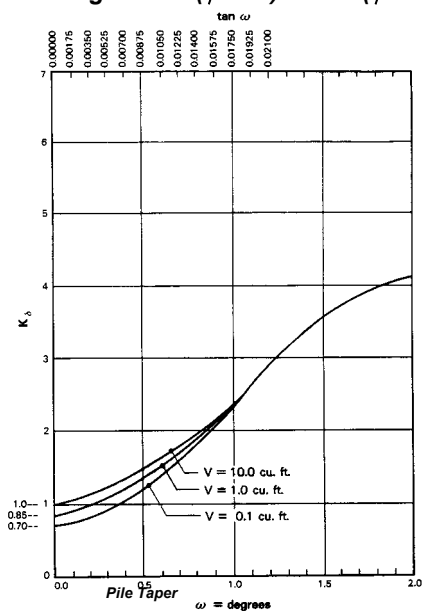


a. Pipe piles and non-tapered portion of monotube piles
b. Timber piles
c. Precast concrete piles
d. Raymond step-taper Piles
e. Raymond uniform taper piles
f. H-piles
g. Tapered portion of monotube piles

Slide 8-1-35

SOILS AND FOUNDATIONS WORKSHOP

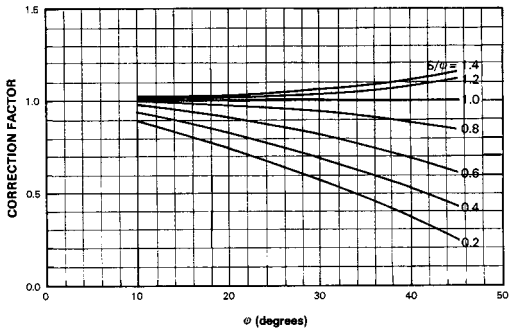
Figure 8-2 (ϕ=25°) to 8-5 (ϕ=40°)



Slide 8-1-36

SOILS AND FOUNDATIONS WORKSHOP

Figure 8-6



Slide 8-1-37

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

SOILS AND FOUNDATIONS WORKSHOP

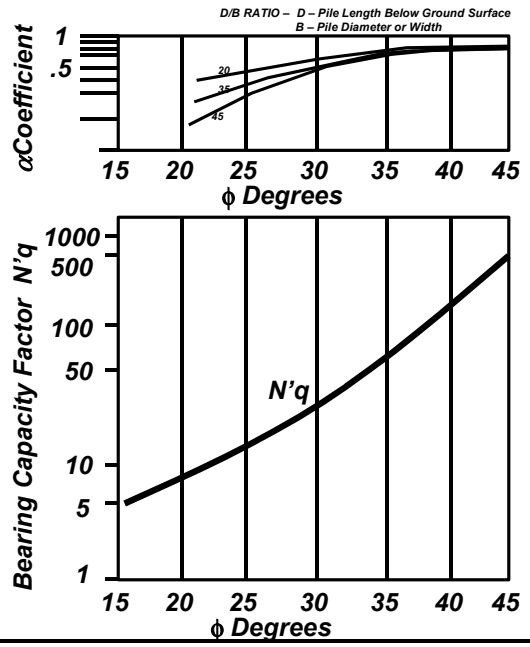
End Bearing Rules Granular Soils (Cont'd)

- 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

SOILS AND FOUNDATIONS WORKSHOP

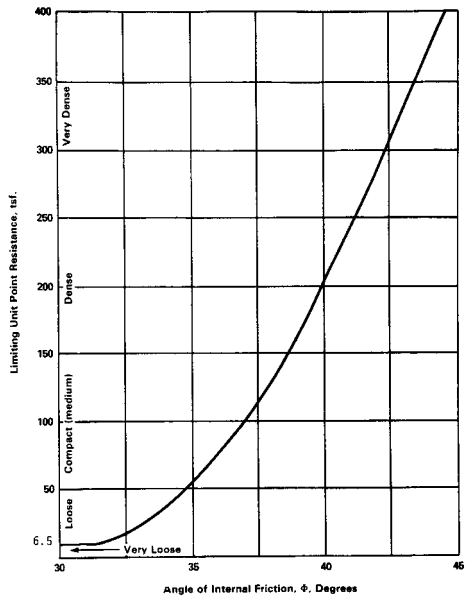
Figure 8-7a



Slide 8-1-40

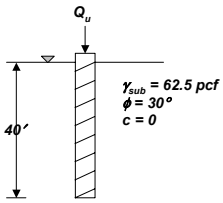
SOILS AND FOUNDATIONS WORKSHOP

Figure 8-7b



Slide 8-1-41

SOILS AND FOUNDATIONS WORKSHOP



$Q_u = A_p\, \alpha P_D N'_q + K_\delta C_F P_d \sin(\delta + \omega)\, C_d D$

Where the following terms are known from the problem

A_p = 1 sq.ft
$P_D = 40\, \gamma_{sub}$ = 2500 psf
$P_d = 20\, \gamma_{sub}$ = 1250 psf
$\omega = 0°$, $D = 40'$, $C_d = 4'$

Solution:

Find Point Resistance, Q_P:

Use Figure 8-7A to Find N'_q and α for $\phi = 30°$

$N'_q = 30$ $\qquad \alpha = 0.5$ (for $\frac{D}{B} = 40$)

$Q_p = A_p \alpha P_D N'_q$

$= (1\text{ sq.ft})(0.5)(2500\text{ psf})\ 30 = 18.75$ tons

Check Limiting Point Resistance from Figure 8-7B

$Q_{Lim} = Q_{Lim}\, A_p = (6.5\text{ tsf})(1\text{ sq.ft}) = 6.5$ tons

$\therefore Q_p = 6.5$ tons

Slide 8-1-42

SOILS AND FOUNDATIONS WORKSHOP

Find Skin Resistance, Q_S:
Use Figures 8-1, 8-3, and 8-6 with $\phi = 30°$

Figure 8-1 – For V = 1 cubic ft. per ft., and curve "C" for precast concrete piles;

$\frac{\delta}{\phi} = 0.76$, Since $\phi = 30°$, $\delta = 22.8°$

Fig. 8-3 – For $\omega = 0$, V = 1 cu.ft/ft ;

$K_\delta = 1.15$

Fig. 8-6 – For $\frac{\delta}{\phi} = 0.76$;

$C_F = 0.9$

$Q_s = K_\delta C_F P_d \sin \delta C_d D$

$Q_s = (1.15)(0.9)(1250\ psf)(\sin 22.8)(4')\ 40'$

$Q_s = 40.1$ tons

$Q_u = 6.5 + 40.1 = 46.6$ tons

Slide 8-1-43

ALLOWABLE LOAD ON PILES IN COHESIVE SOILS

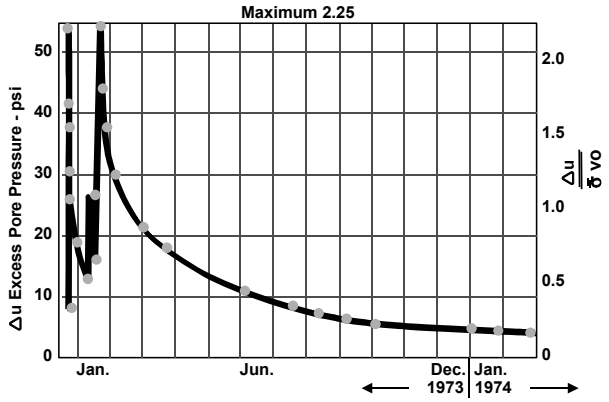
- *General failure mechanism well understood*
- *Pile capacity immediately after driving is affected by excess pore pressures*
- *Long term pile capacity is based on reconsolidated soil strength*

Slide 8-1-44

Slide 8-1-45

Pore Pressure – South Bay Bridge

Pier No. 3, Piezometer Nos. 1 & 2



Slide 8-1-46

Ultimate Capacity of Piles in Cohesive Soils

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

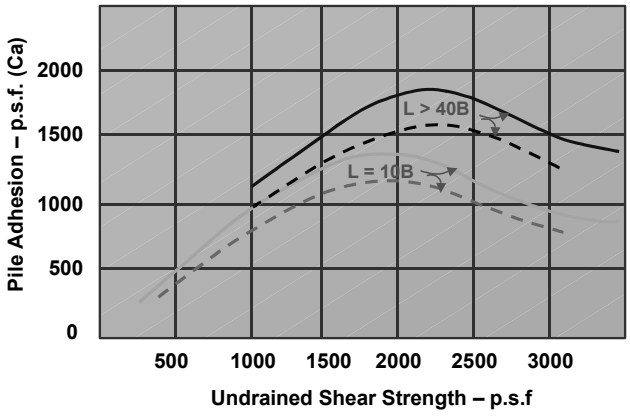
Slide 8-1-47

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

Effect of Pile Embedment on Adhesion in Cohesive Soils



Slide 8-1-49

SOILS AND FOUNDATIONS WORKSHOP

Static Analysis Equation Cohesive Soils

$$Q_{ULT} = C_a \quad C_d\, D \quad + \; 9\, C_u \quad A_p$$

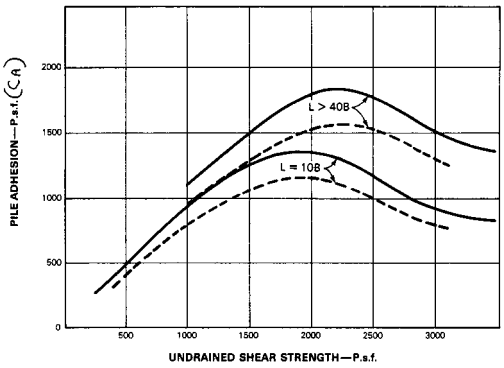
(Adhesion) (Pile Surface Area)+ (Shear Strength)(Point Area)

*** Remember end bearing mobilization requires a pile tip movement of about 10% of pile diameter*

Slide 8-1-50

SOILS AND FOUNDATIONS WORKSHOP

Figure 8-8
Adhesion values for piles in cohesive soils



Legend: L = Distance from ground surface to bottom of clay layer or pile tip; whichever is less
B = Pile diameter

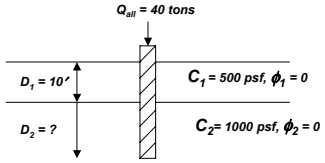
Concrete, timber, corrugated steel piles
Smooth steel piles

Reference: Based on Tomlinson 1979

Slide 8-1-51

SOILS AND FOUNDATIONS WORKSHOP

Example: Determine the Required Pile Length To Resist A 40 Ton Load with A Safety Factor Of 2. Assume No Point Capacity For the 1′ Square Precast Concrete Pile.



Solution:

$Q_u = C_{a1} C_{d1} D_1 + C_{a2} C_{d2} D_2$

$C_{d1} = C_{d2} = 4 \times 1' = 4'$

From Figure 8-8, find C_a for a rough pile

C_{a1} = 500 psf (L=10B)
C_{a2} = 1100 psf (Assume L > 40B)

Q_u = 40 tons × 2 = 80 tons = (500 psf)(4′)(10′) + (1100 psf)(4′)D_2

$$D_2 = \frac{80 - 10}{2.2} = 32'$$

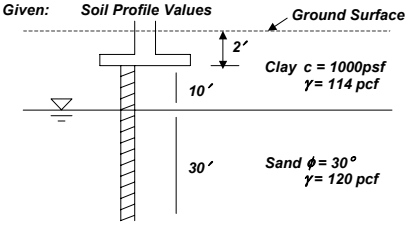
∴ Total pile length required = 32′ + 10′ = 42′

Slide 8-1-52

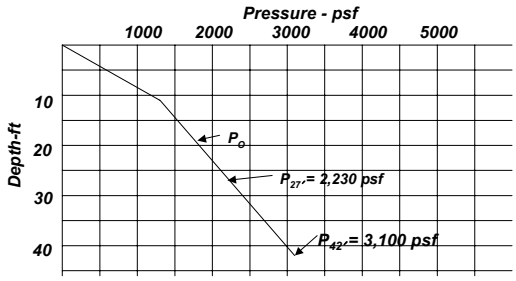
SOILS AND FOUNDATIONS WORKSHOP

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.

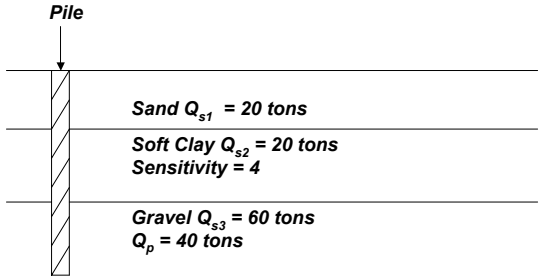


Slide 8-1-53

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.



Slide 8-1-54

SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY

Site Exploration

Basic Soil Properties

Laboratory Testing

Slope Stability

Embankment Settlement

Spread Footing Design

PILE DESIGN

- ***Static Analysis – Pier***
  - ***Pipe Pile***
  - ***H – Pile***
- ***Abutment***
  - ***Pipe Pile***
  - ***H – Pile***
- ***Driving Resistance***
- ***Abutment Lateral Movement***

Construction Aspects

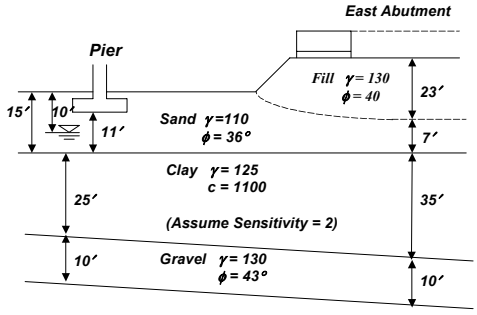
Slide 8-1-55

SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY

PILE FOUNDATION DESIGN

ASSUME SOIL PROFILE VALUES BELOW



- ***Pile Minimum Depth***
- ***Pile Material***
- ***Pile Shape***
- ***Driving Resistance***
- ***Pre-augering for Abutment Piles***
- ***Other issues?***

Slide 8-1-56

SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY
PILE DESIGN

Design Soil Profile

Strength value selected for all layers.

Static Analysis - Pier

12" - 70 T Pipe Pile - 36' length required
12" - 120 T H-Pile - 46' length required.

Static Analysis Abutment

12" - 70 T Pipe Pile - 65' length required
12" - 120 T H-Pile - 75' length required.

Driving Resistance

Driving Resistances computed for both pipe (max 216 T) and H-piles (max 345 T) to permit design check of pile section overstress.

Pipe pile will require pre-augering through embankment.

Slide 8-1-57

SOILS AND FOUNDATIONS WORKSHOP

Deep Foundation Design - Load Capacity

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

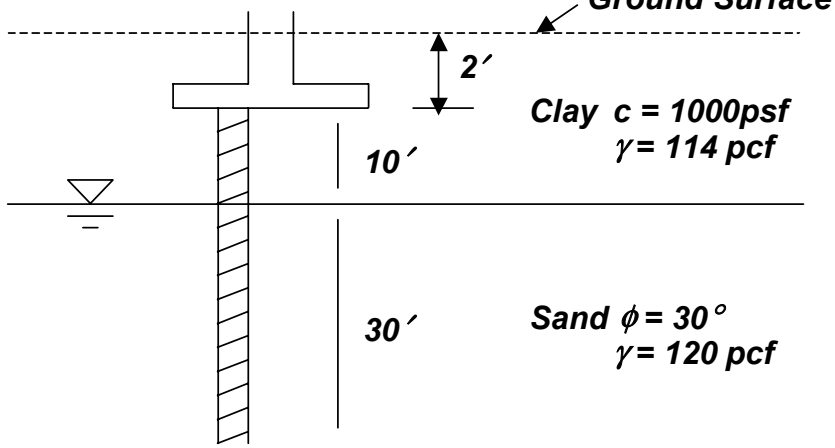
Activities: Static analysis computation and interpretation of results

Slide 8-1-58

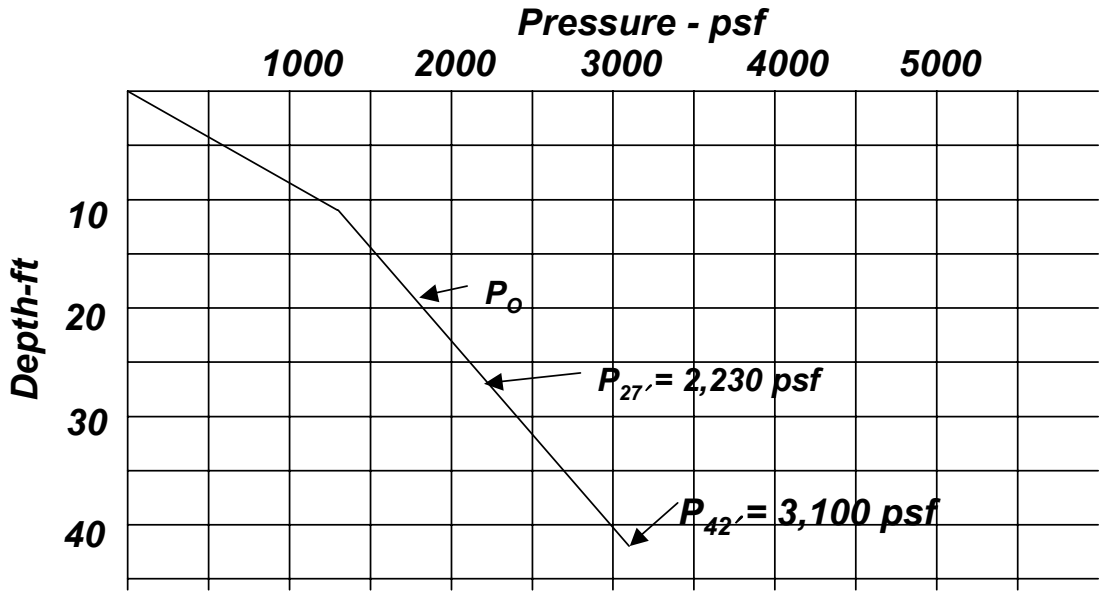
SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 7
Static Pile Analysis

Given: Soil Profile Values



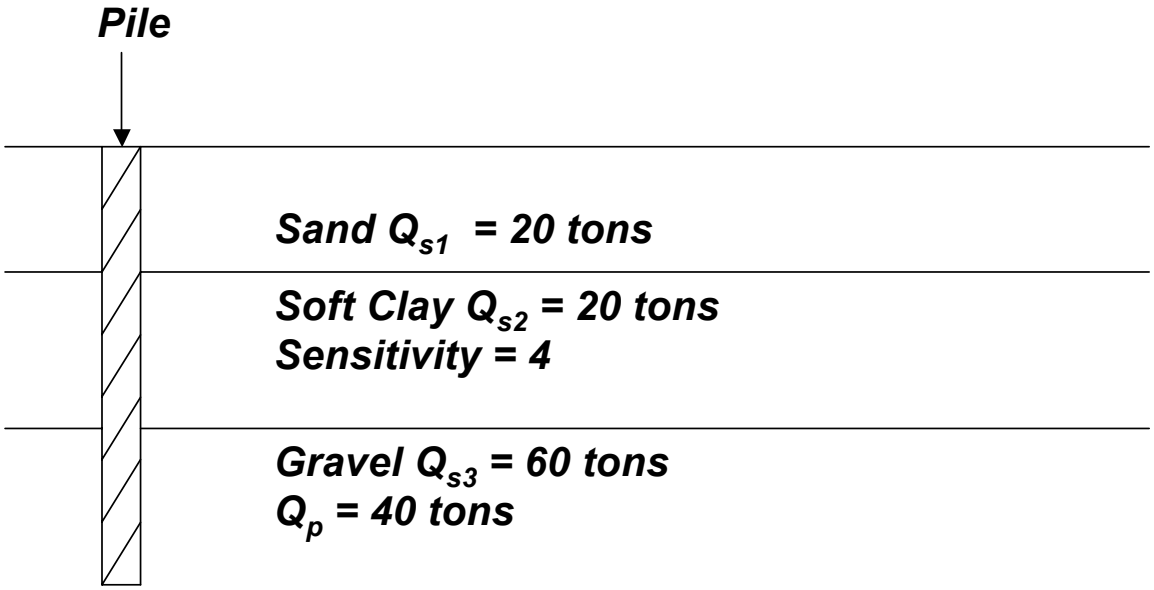
Find the Capacity of the 40′ Long 12″ Square Concrete Pile Shown Below. Use the Information Given in Both the Soil Profile and Pressure Diagram.



SOILS AND FOUNDATIONS WORKSHOP

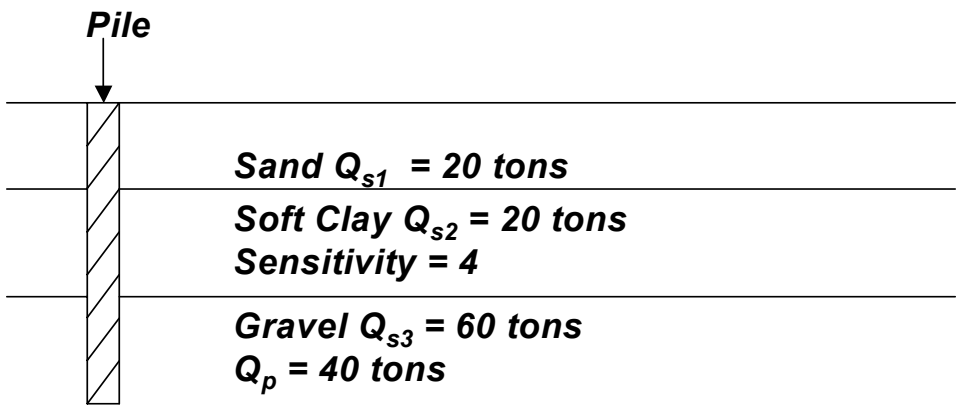
Mini - Exercise

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



$$\text{Ultimate capacity} = Q_{s3} + Q_P = 60 + 40 = 100 \text{ tons}$$

$$\text{Driving capacity} = Q_{s1} + (Q_{s2}\text{Sensitivity}) + Q_{s3} + Q_P$$

$$= 20 + \frac{20}{4} + 60 + 40 = 125 \text{ tons}$$

$$\text{Restrike capacity} = Q_{s1} + Q_{s2} + Q_{s3} + Q_P$$

$$= 20 + 20 + 60 + 40 = 140 \text{ tons}$$

LESSON 8

TOPIC 2

Deep Foundation – Pile Groups

DEEP FOUNDATION DESIGN

Lesson 8 - Topic 2
Pile Groups

Slide 8-2-1

DEEP FOUNDATION DESIGN
Pile Groups

1. Recognize the Effects of Pile Spacing, Settlement and Negative Skin Friction

ACTIVITY: Question-Answer

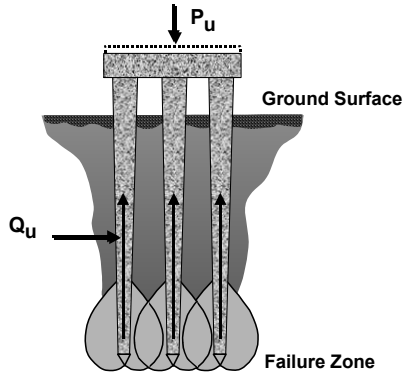
Slide 8-2-2

Pile Group Failure Modes

- ***Individual Pile Failure***
- ***Block Failure***

Slide 8-2-3

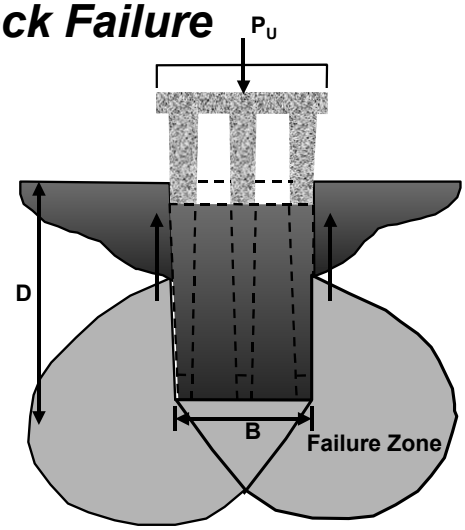
Individual Pile Failures



$P_u = n\ Q_u\ E$ n = Number of Piles
E = Group Efficiency

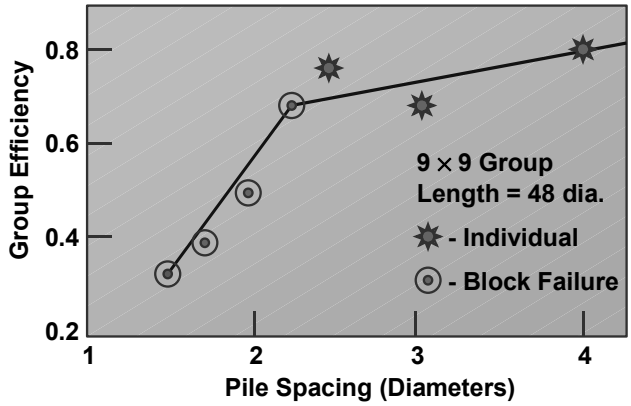
Slide 8-2-4

Block Failure



Slide 8-2-5

Group Efficiency Vs. Pile Spacing in Clay



Slide 8-2-6

Pile Group Capacity in Sand

- ***For general sand case use E = 100%***

$$P_{ult} = n\ Q_{ult}$$

Slide 8-2-7

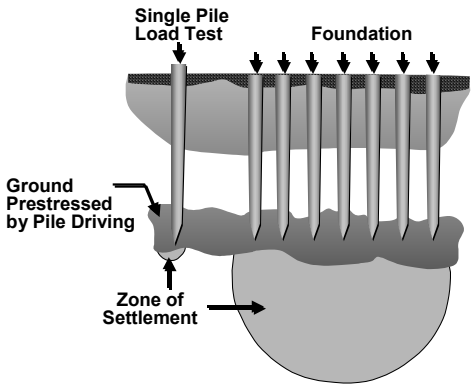
Pile Group Capacity in Clay

- ***For center to center pile spacing of 3D***
  - ***E = 70%***
- ***For center to center pile spacing of 6D***
  - ***E = 100%***

$$P_{ult} = n\ E\ Q_{ult}$$

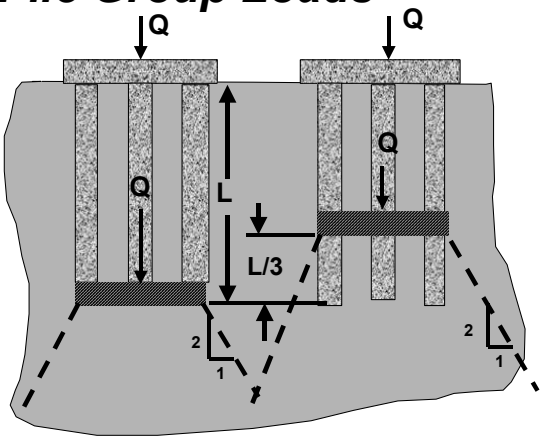
Slide 8-2-8

Settlement of Pile Groups in Sand (After Skempton)



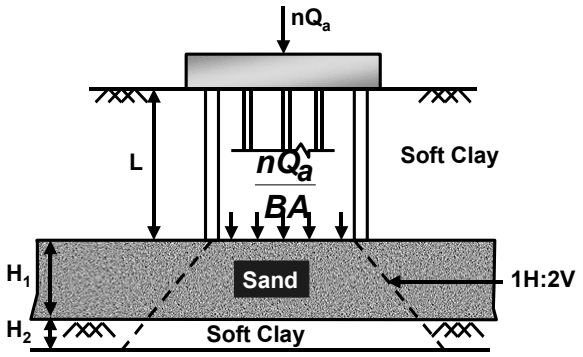
Slide 8-2-9

General Concept of Distribution of Pile Group Loads



Slide 8-2-10

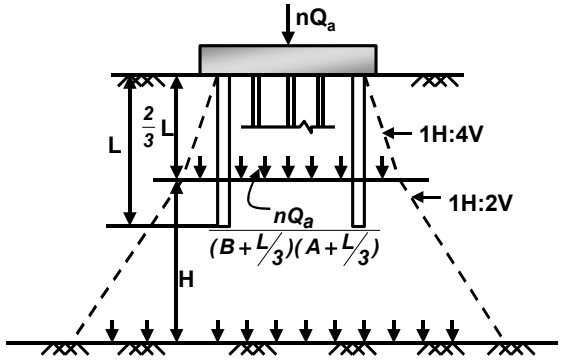
Example Pressure Distribution for End Bearing Pile Groups



A, B = Pile Group Dimensions

Slide 8-2-11

Example Pressure Distribution for Friction Pile Groups



B, A = Pile Group Dimensions

Slide 8-2-12

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

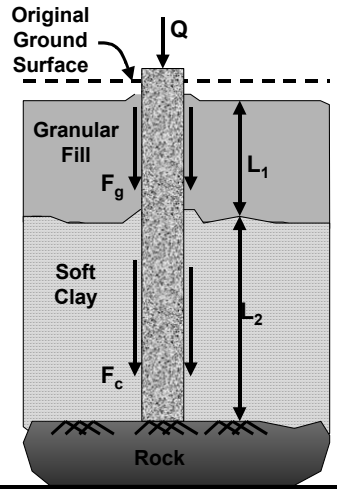
e_o = Initial voids ratio

P_O = Overburden Pressure

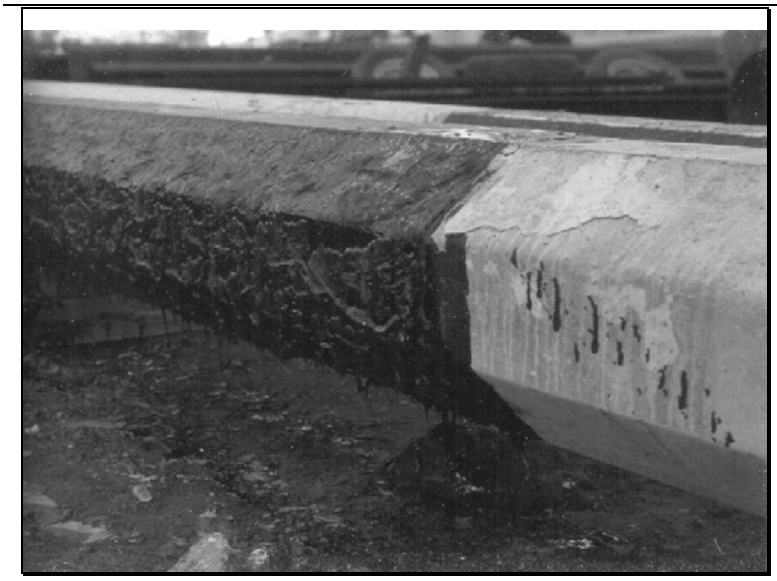
ΔP = Change in Pressure

Slide 8-2-13

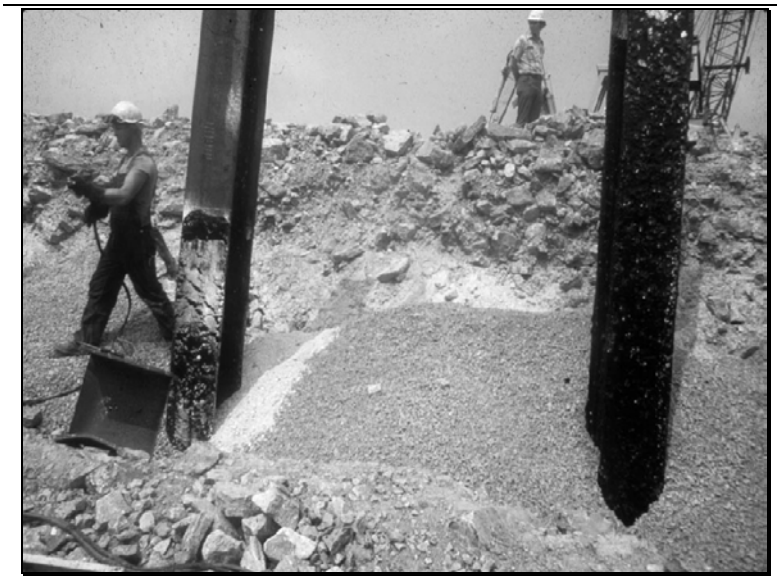
Negative Skin Friction



Slide 8-2-14



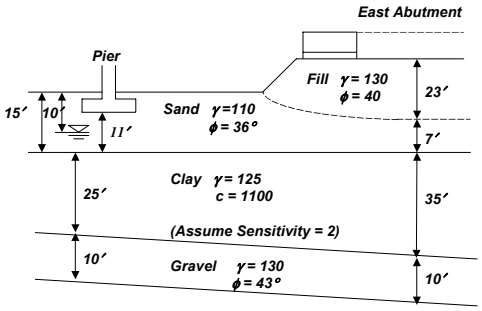
Slide 8-2-15



Slide 8-2-16

SOILS AND FOUNDATIONS WORKSHOP

Assume Soil Profile Values Below



Consider Pile Group Problems at This Site.

Slide 8-2-17

SOILS AND FOUNDATIONS WORKSHOP

Deep Foundation Design - Pile Groups

- ***Recognize the effect of pile spacing, settlement, and negative skin friction***

Activities: Question - Answer

Slide 8-2-18

LESSON 9

TOPIC 1

Construction Monitoring and Quality Assurance

CONSTRUCTION MONITORING AND QUALITY ASSURANCE

Lesson 9 - Topic 1

Instrumentation

Slide 9-1-1

CONSTRUCTION MONITORING AND QUALITY ASSURANCE

1. Recall the Basic Types of Geotechnical Instrumentation

ACTIVITY: Question-Answer

Slide 9-1-2

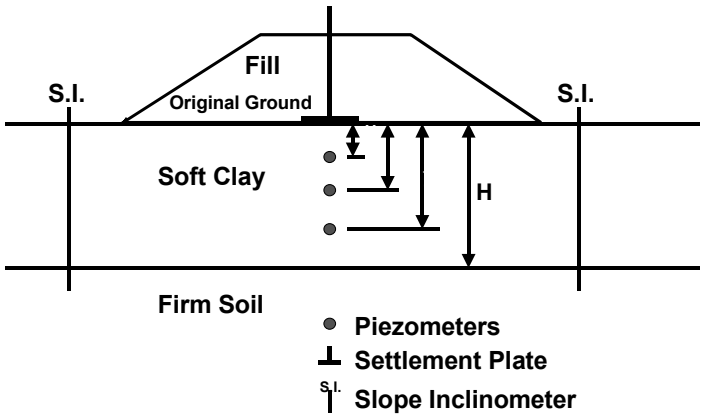
Construction Observation and Monitoring

- ***Visual***
- ***Instrumentation***

Slide 9-1-3

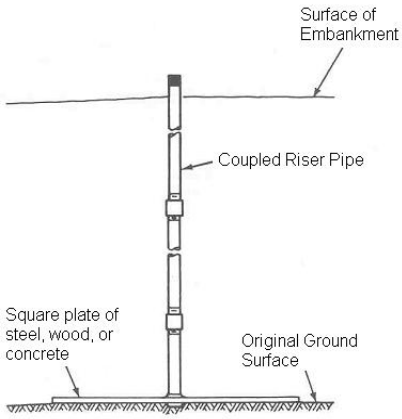
Slide 9-1-4

Typical Instrumentation Plan



Slide 9-1-5

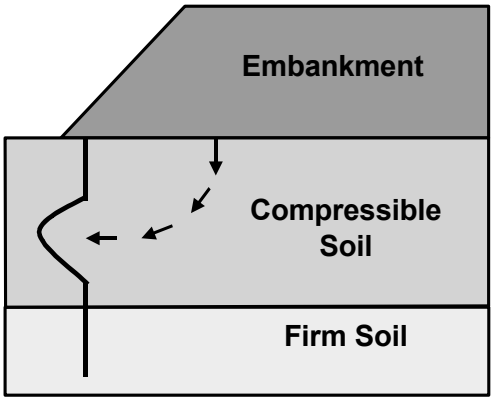
Settlement Platform Schematic



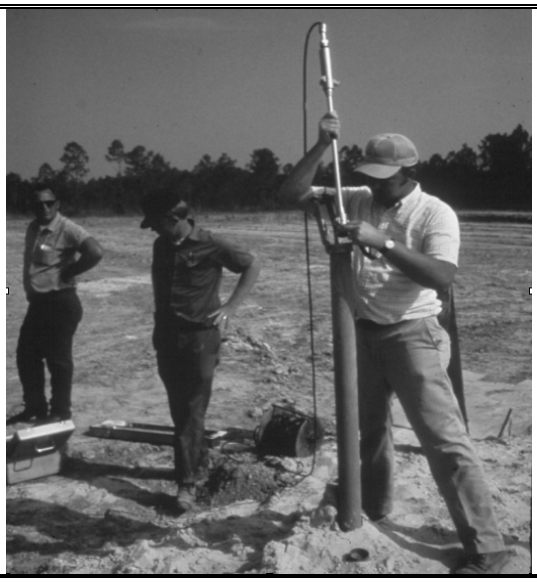
Slide 9-1-6

Slide 9-1-7

Vertical Inclinometer

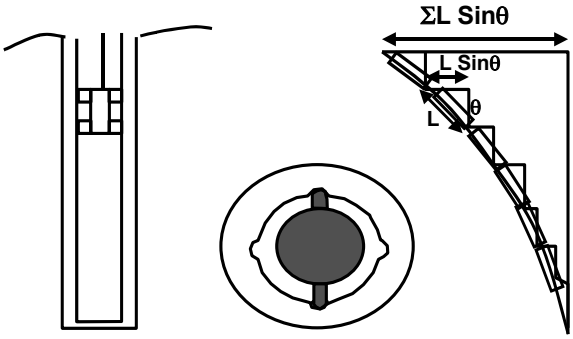


Slide 9-1-8



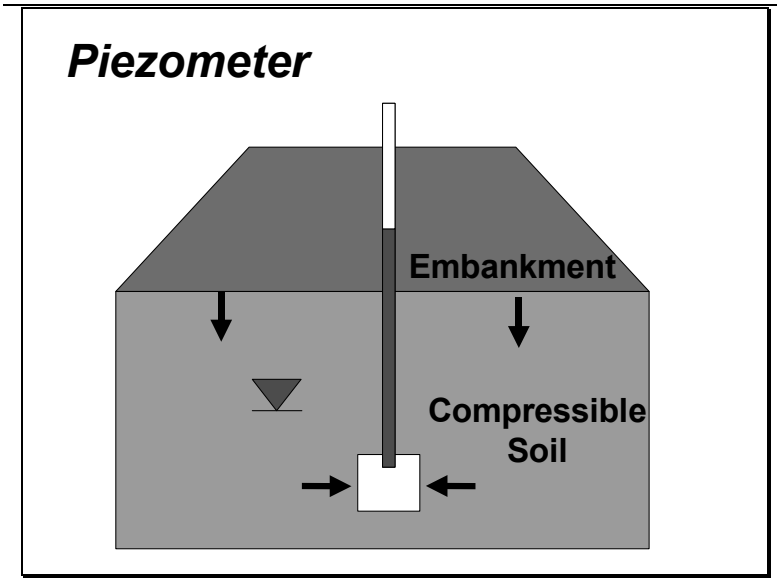
Slide 9-1-9

Principle of Inclinometer Operation

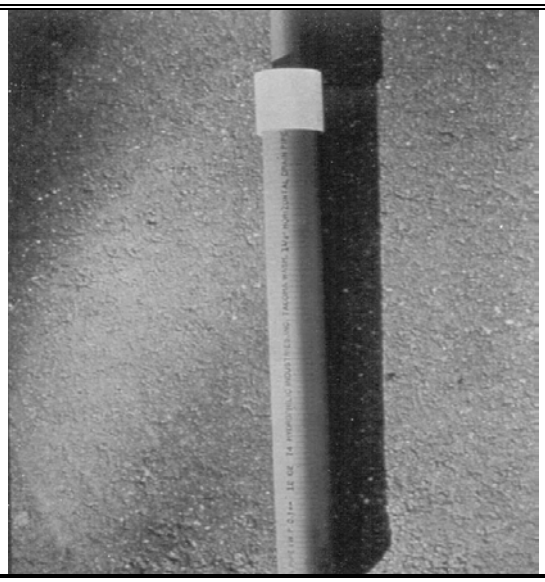


L = Distance between readings
θ = Angle measured by sensor

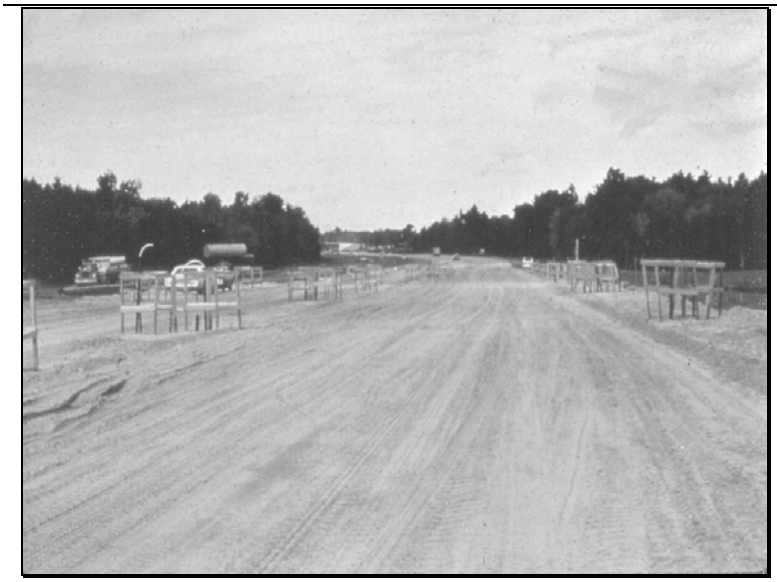
Slide 9-1-10



Slide 9-1-11

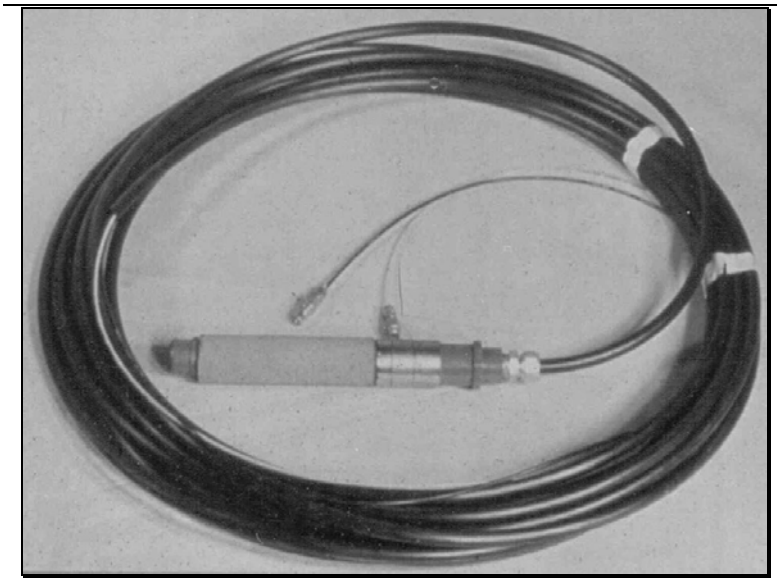


Slide 9-1-12



Slide 9-1-13

Slide 9-1-14

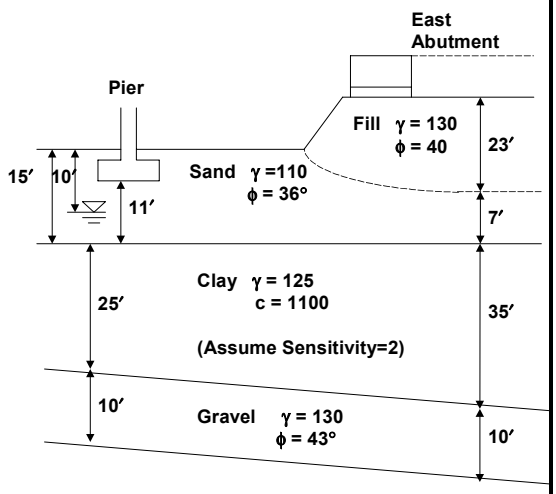


Slide 9-1-15

Slide 9-1-16

SOILS AND FOUNDATIONS WORKSHOP

Propose geotechnical instrumentation for the Apple Freeway embankment



Slide 9-1-17

SOILS AND FOUNDATIONS WORKSHOP

Construction Monitoring and Quality Assurance

- ***Recall the basic types of geotechnical instrumentation***

Activities:

Question-Answer

Slide 9-1-18

LESSON 9

TOPIC 2

Construction Monitoring and Quality Assurance - Foundations

CONSTRUCTION MONITORING AND QUALITY ASSURANCE

Lesson 9 - Topic 2
Foundations

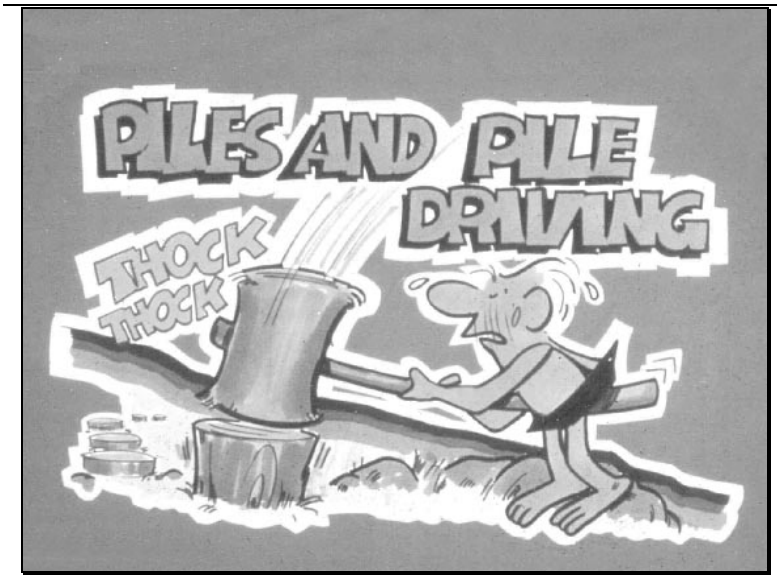
Slide 9-2-1

CONSTRUCTION MONITORING AND QUALITY ASSURANCE
Foundations

1. Apply Dynamic Analysis to Pile Design
2. Evaluate Pile Equipment Acceptability

ACTIVITY: Wave Equation Applications

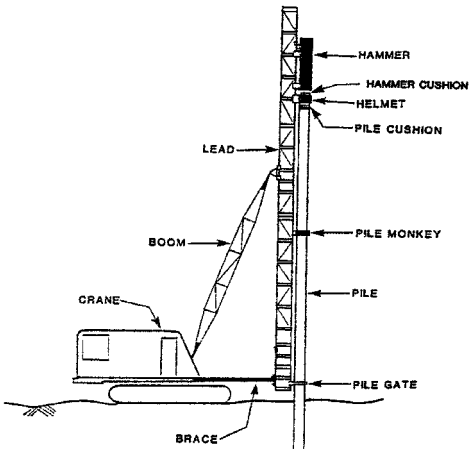
Slide 9-2-2



Slide 9-2-3

Both the Pile and the Driving Equipment Must Be Sized to Permit Pile Installation to the Designed Length Without Damage

Slide 9-2-4

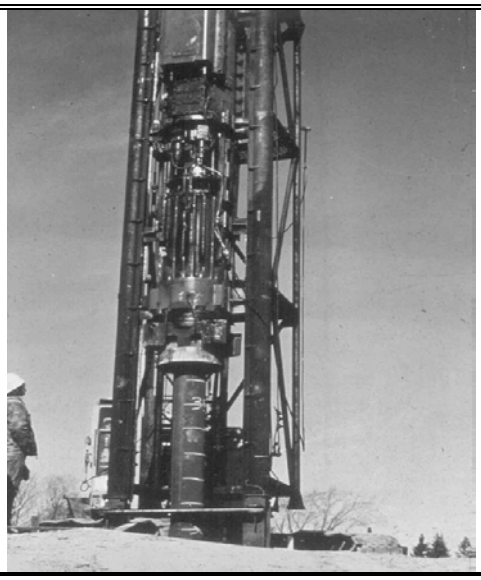


Pile Support System

Slide 9-2-5

Slide 9-2-6

Slide 9-2-7



Slide 9-2-8

Slide 9-2-9

Driving System Analysis

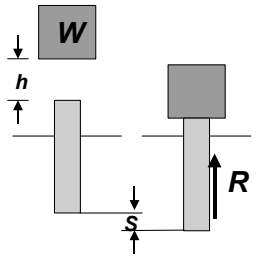
Slide 9-2-10

The Fundamental Pile Driving Formula

Hammer Energy = Work of Soil Resistance

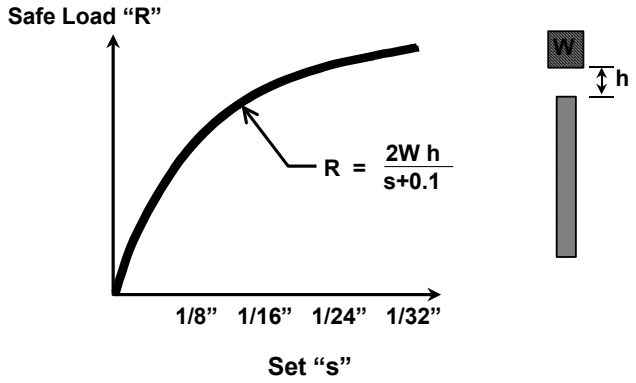
$$W\,h = R\,s$$

$$R = \frac{W\,h}{s}$$

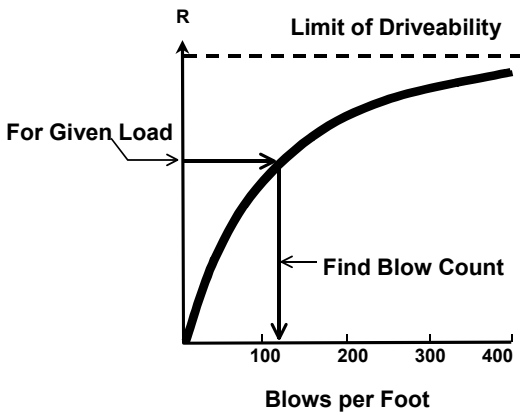


Slide 9-2-11

The ENR Bearing Graph

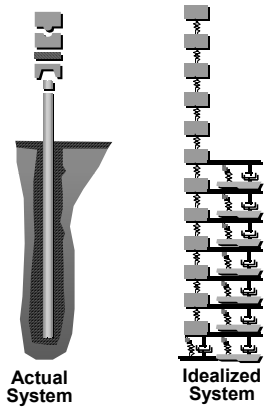


Slide 9-2-12

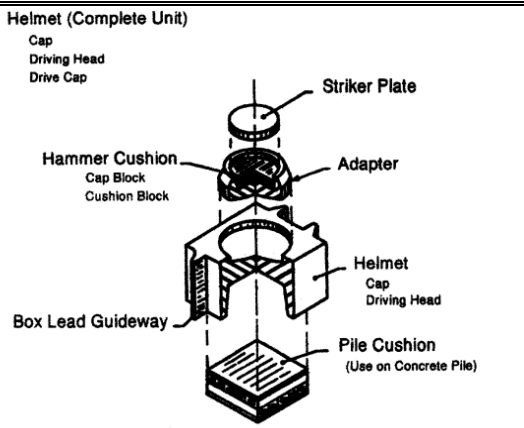


Slide 9-2-13

Comparison of A Typical Hammer-Pile-Soil System to Smith's Idealization



Slide 9-2-14



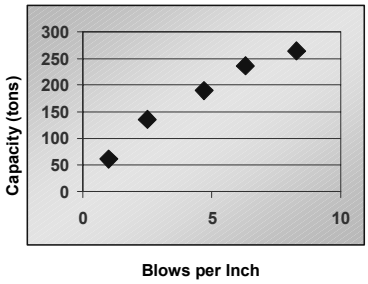
Note: The helmet shown is for nomenclature only. Various sizes and types are available to drive H, pipe, concrete (shown) and timber piles. A system of inserts or adapters is utilized up inside of the helmet to change from size to size and shape to shape.

Slide 9-2-15

Pile Driving Analysis – Wave Equation Output

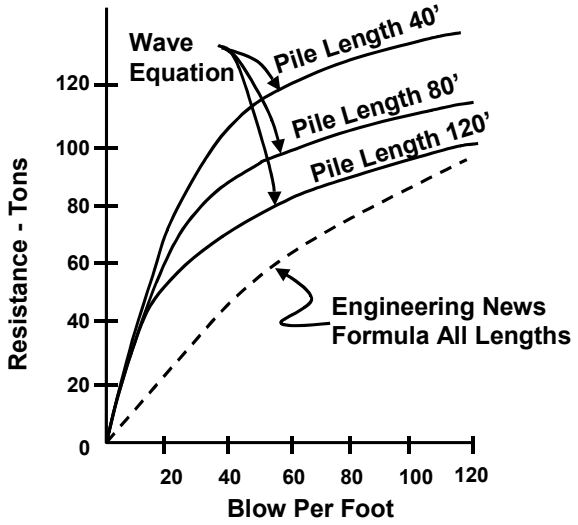
14" Square Prestressed Concrete Pile

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

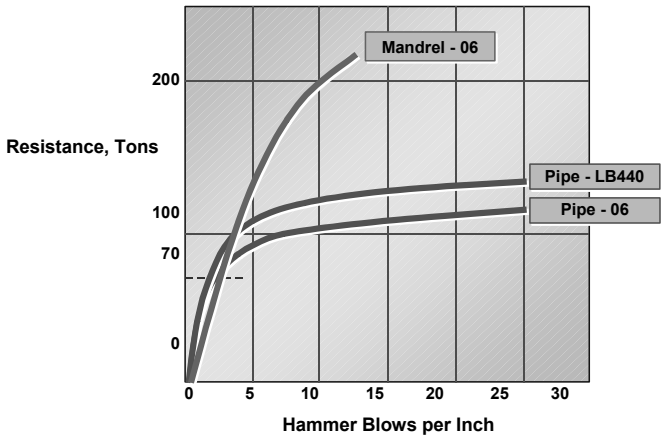


Slide 9-2-17

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



Slide 9-2-19

Slide 9-2-20

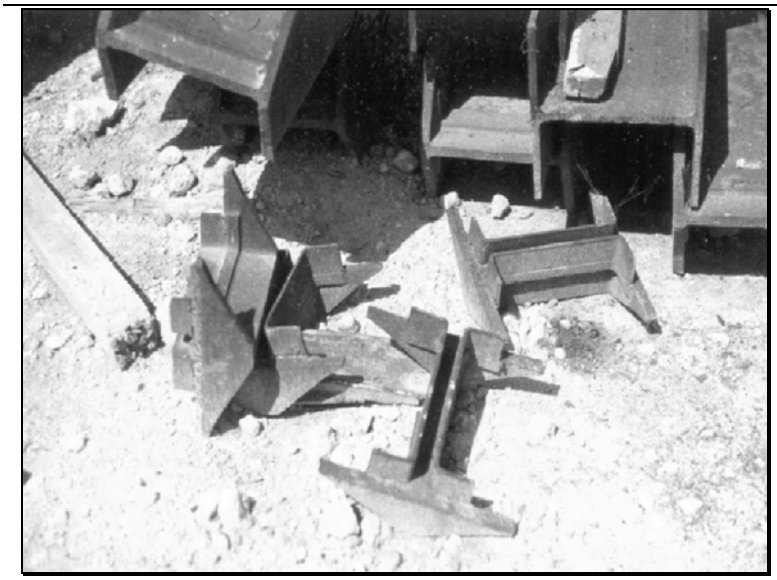
Allowable Stress Levels in Piles

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

Slide 9-2-22

Slide 9-2-23



Slide 9-2-24

Construction Considerations in Design

Intelligent Preparation of Plan and Specifications Can Only Be Done By One Who Understands the Construction Operation As Well as Structural Design Concepts

Slide 9-2-25

SOILS AND FOUNDATIONS WORKSHOP

Standard Specifications

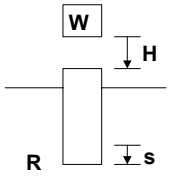
"In the Absence of Pile Load Tests the Safe Bearing Value for Piles Shall be Determined by the Following Formulae:

ENR Formulae or Modifications"

Slide 9-2-26

SOILS AND FOUNDATIONS WORKSHOP

ENR Formula Factor of Safety



Fundamental Formula

$W^{\#}H(ft) = R^{\#}s(ft)$

$$R = \frac{WH}{s}$$

Where R = ultimate soil resistance

ENR Formula

$$P = \frac{2\,W^{\#}H(ft)}{s(in) + 0.1}$$

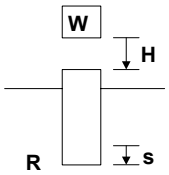
Where P = design load in #

Slide 9-2-27

SOILS AND FOUNDATIONS WORKSHOP

ENR Formula Factor of Safety

To find F.S. between P and R, revise ENR to be dimensionally correct and compare the resulting equation for P with R



$$R = \frac{WH}{s}$$

$$P = \frac{2\,W^{\#}H(ft)}{s(in) + 0.1}$$

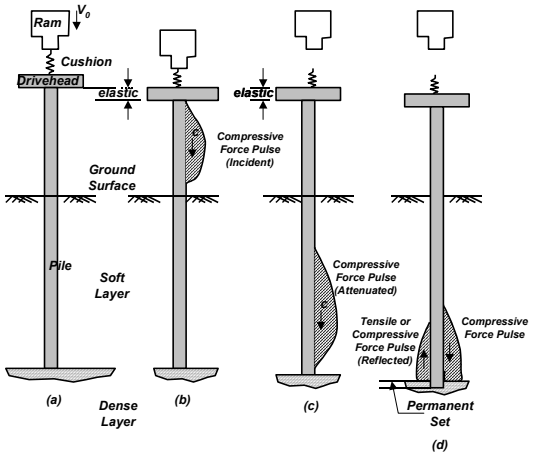
$$P = \frac{2WH}{s + 0.1}(1/12) = \frac{WH}{6s}$$

$$R = 6P$$

Safety Factor = 6

Slide 9-2-28

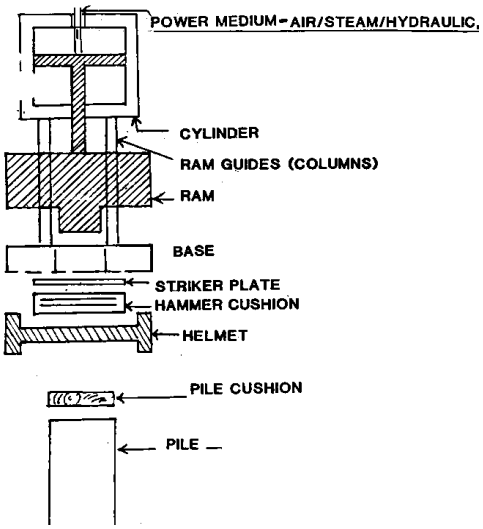
SOILS AND FOUNDATIONS WORKSHOP



Slide 9-2-29

SOILS AND FOUNDATIONS WORKSHOP

Important Driving System Properties



Slide 9-2-30

SOILS AND FOUNDATIONS WORKSHOP

IMPORTANT PILE PROPERTIES

1. LENGTH

2. CROSS SECTIONAL AREA

other contributing pile properties

3. MATERIAL

4. DAMPING

Slide 9-2-31

SOILS AND FOUNDATIONS WORKSHOP

Instructor Demonstration of Pile Stiffness

Slide 9-2-32

SOILS AND FOUNDATIONS WORKSHOP

IMPORTANT

SOIL VALUES

DISTRIBUTION OF SOIL RESISTANCE IN FRICTION & POINT BEARING

DAMPING

QUAKE

TOTAL SOIL RESISTANCE TO BE OVERCOME DURING DRIVING TO ESTIMATED LENGTH

Slide 9-2-33

SOILS AND FOUNDATIONS WORKSHOP

2. The Output of most interest is the summary table of extreme values for all the ultimate resistances analyzed.

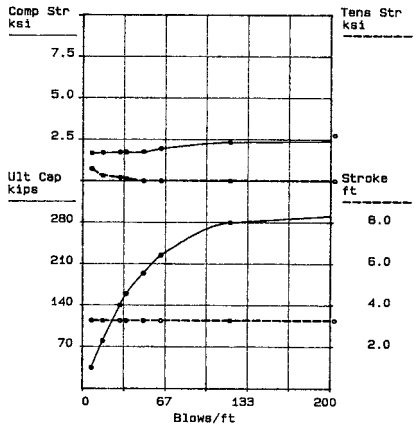
WAVE EQUATION SUMMARY

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

SOILS AND FOUNDATIONS WORKSHOP

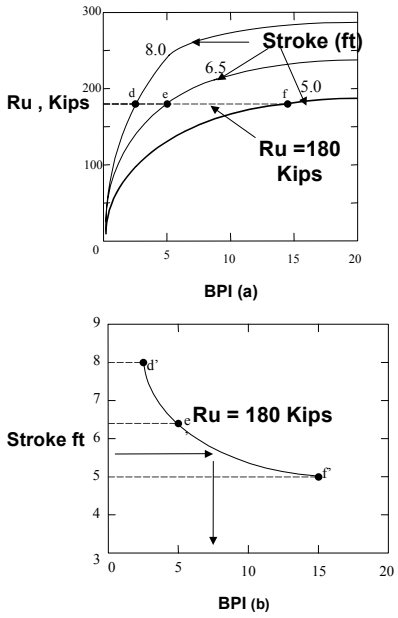
The data from the summary table of wave equation output is usually plotted to produce curves of blow count versus resistance and stress.



WAVE EQUATION BEARING GRAPH

Slide 9-2-35

SOILS AND FOUNDATIONS WORKSHOP



Slide 9-2-36

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

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

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.***

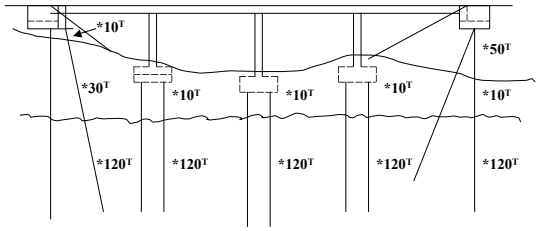
2. ***For concrete piles, the allowable driving stresses are:***
   - ***Compressive stress allowed = 0.85 F'c – prestress = 3400 – 700 = 2700 psi, actual Max. compressive stress up to 225 Kips from wave equation output summary is 1.96 ksi or 1960 psi ≤ 2700 psi allowed value. O.K.***
   - ***Tensile stress allowed = $3\sqrt{F'c}$ + 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

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

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

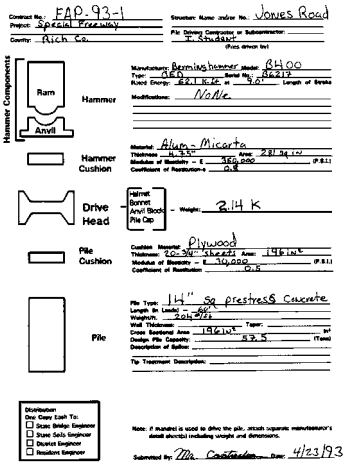
Slide 9-2-41

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

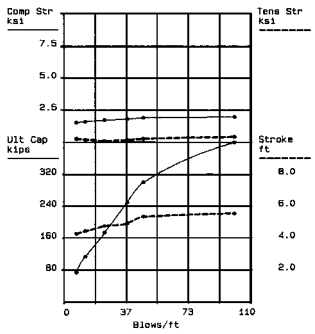
SOILS AND FOUNDATIONS WORKSHOP

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

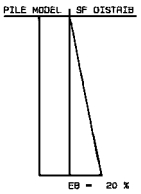
G R L W E A P – Federal Highway Admin.
S&F STUDENT EXERCISE HAMMER APPROVAL 01/29/93



BRMNGHMR B400/5.0
Efficiency .720
Helmet 2.14 kips
H Cushion 20705 k/in
P Cushion 511 k/in

G = .100 .100 in
J = .050 .100 s/ft

Pile Length 60.00 ft
P-Top Area 196.00 in2



Slide 9-2-44

SOILS AND FOUNDATIONS WORKSHOP

Construction Monitoring and Quality Assurance

- ***Apply dynamic analysis to pile design***
- ***Evaluate pile equipment acceptability***

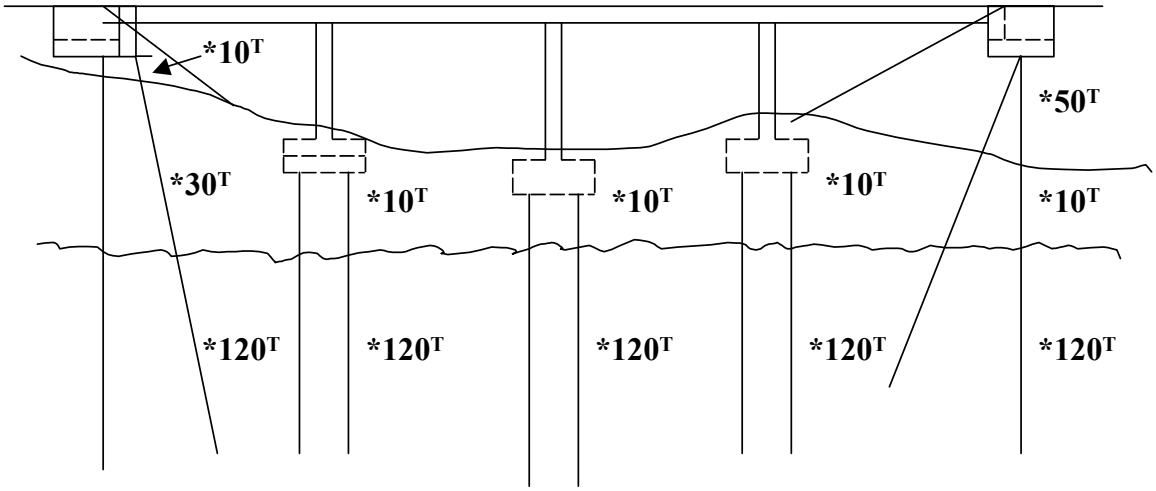
Activities: Wave Equation Applications

Slide 9-2-46

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

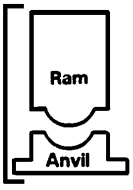
STUDENT EXERCISE NO. 9
Hammer Approval

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

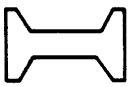
Contract No.: FAP-93-1 Structure Name and/or No.: Jones Road
Project: Special Freeway
County: Rich Co. Pile Driving Contractor or Subcontractor: I. Student (Piles driven by)

Hammer Components



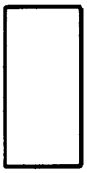
Hammer
Manufacturer: Berminghammer Model: BH00
Type: DED Serial No.: B6217
Rated Energy: 62.1 ft-kt at 9.0' Length of Stroke
Modifications: None

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: 2.14 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

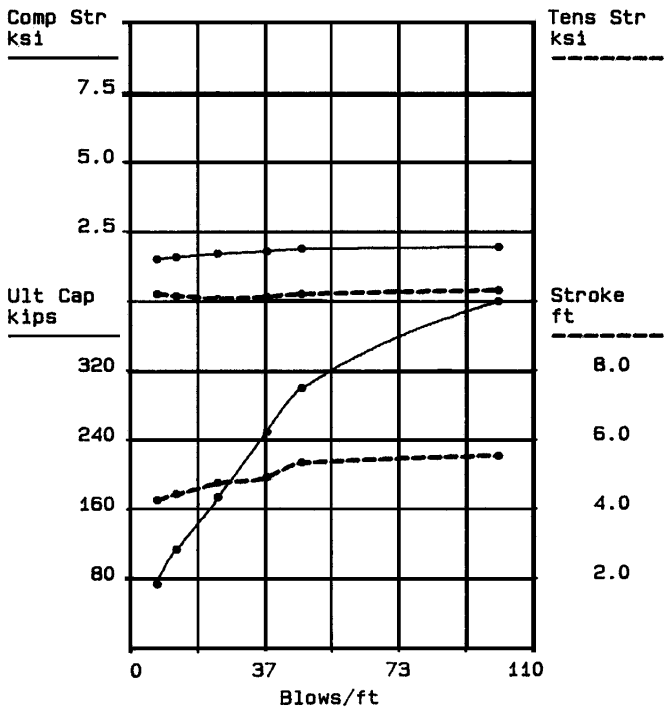
STUDENT EXERCISE NO. 9 (CONT'D)

Federal Highway 01/28/93 GRLWEAP S&F STUDENT EXERCISE HAMMER APPROVAL

Rut kips	Bl Ct bpf	Stroke (ft) down	Stroke (ft) 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

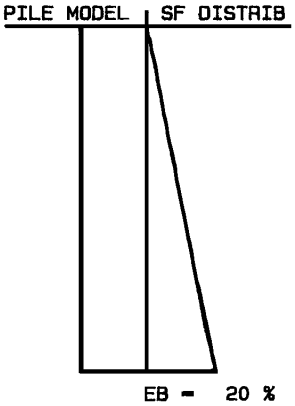
G R L W E A P - Federal Highway Admin.

S&F STUDENT EXERCISE HAMMER APPROVAL 01/29/93



BRMNGHMR B400/5.0

Efficiency	.720	
Helmet	2.14	kips
H Cushion	20705	k/in
P Cushion	511	k/in
Q = .100	.100	in
J = .050	.100	s/ft
Pile Length	60.00	ft
P-Top Area	196.00	in2



LESSON 9

TOPIC 3

Construction Monitoring and Quality Assurance

CONSTRUCTION MONITORING AND QUALITY ASSURANCE

Lesson 9 - Topic 3

Pile Load Testing

Slide 9-3-1

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

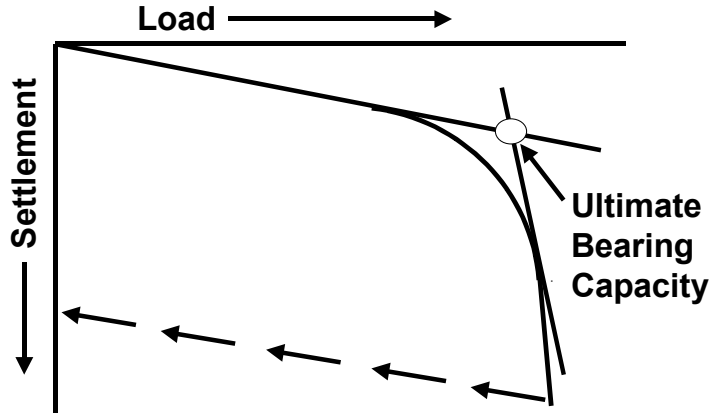
Slide 9-3-3

Pile Load Testing

Pile Load Testing is the Most Positive Method of Determining Pile Capacity.

Slide 9-3-4

Load - Settlement Graph



Slide 9-3-5

Types of Load Tests

Routine

- ***Static***
- ***Dynamic***

Recently Developed

- ***Osterberg Cell***
- ***Statnamic***

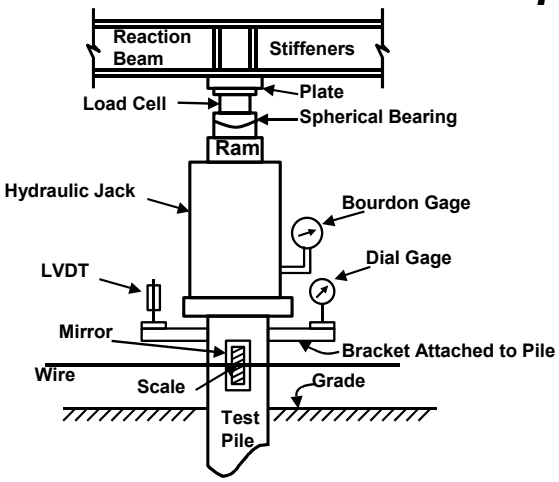
Slide 9-3-6

Static Load Test Types ASTM D1143

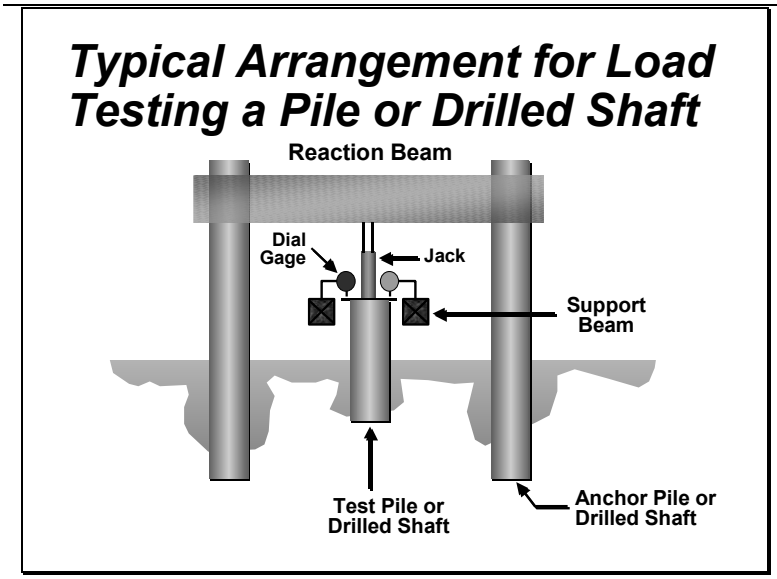
- ***Maintained Load***
- ***Quick Load (Texas Quick Test)***
- ***Constant Rate of Penetration (CRP)***

Slide 9-3-7

Static Load Test - Test Setup



Slide 9-3-8

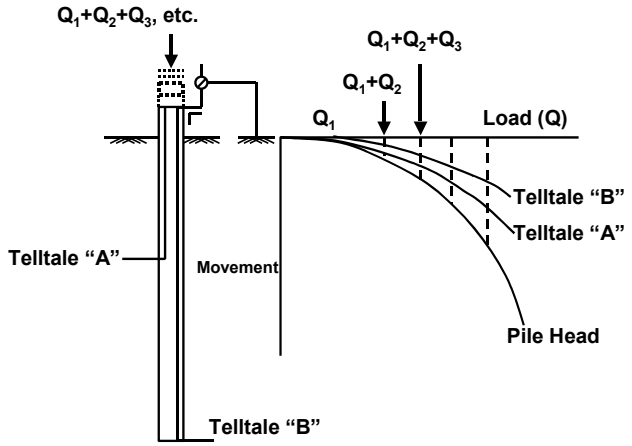


Slide 9-3-9

Slide 9-3-10

Slide 9-3-11

Static Load Test - Mechanism



Slide 9-3-12

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***

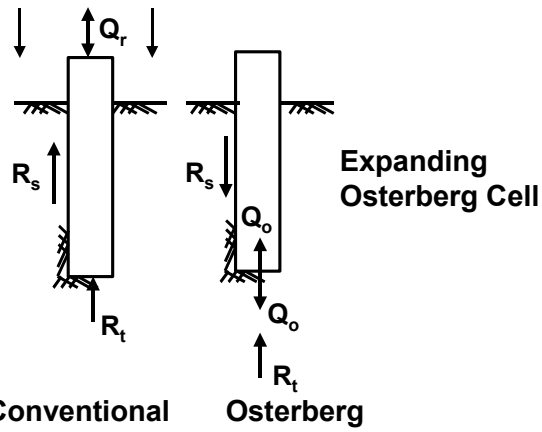
Slide 9-3-13

Slide 9-3-14

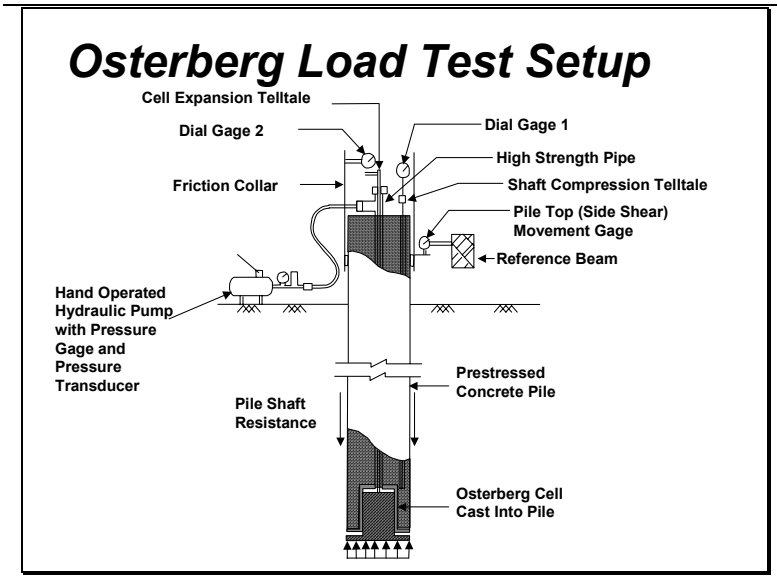
Slide 9-3-15

Osterberg Load Test Concept

Reaction System



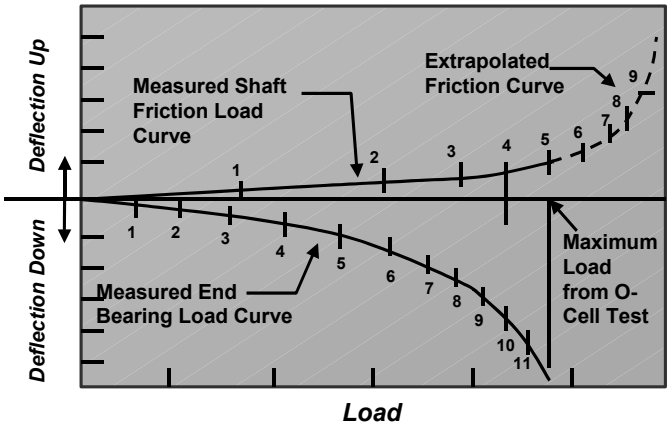
Slide 9-3-16



Slide 9-3-17

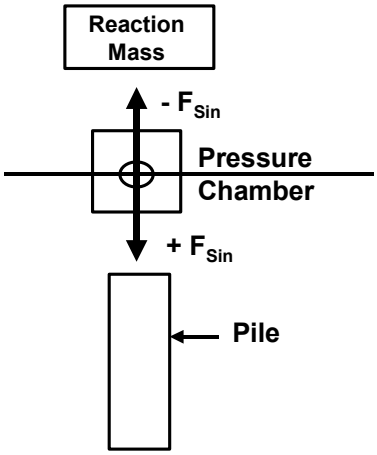
Slide 9-3-18

Osterberg Load Test Mechanism



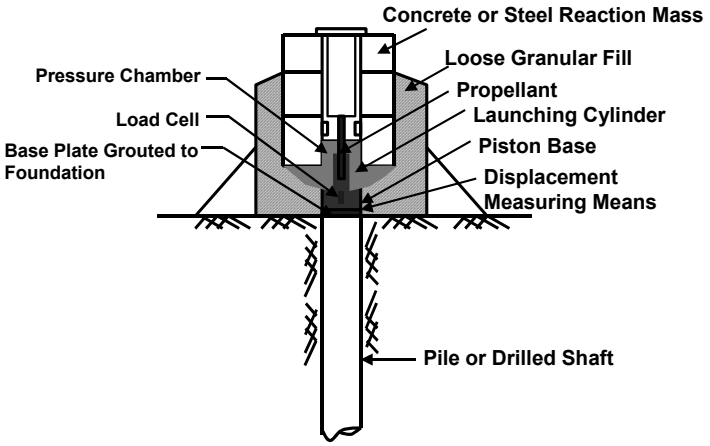
Slide 9-3-19

Statnamic Load Test Concept



Slide 9-3-20

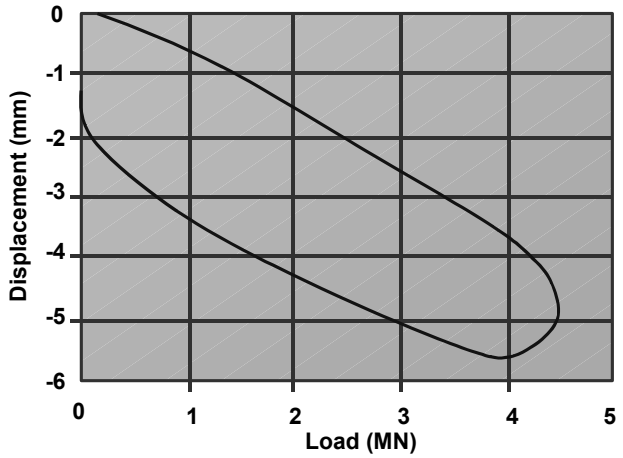
Statnamic Load Test Setup



Slide 9-3-21

Slide 9-3-22

Statnamic Load Test Mechanism



Slide 9-3-23

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

West Seattle Freeway Bridge

Slide 9-3-25

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

Slide 9-3-27

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

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 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

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

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

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

SOILS AND FOUNDATIONS WORKSHOP

What Methods of Deep Foundation Load Testing Have Been Used in the Past 5 Years?

Slide 9-3-34

SOILS AND FOUNDATIONS WORKSHOP

Load Testing Points To Remember

- ***Detailed Soil Investigation***
- ***Technically Qualified Staff to Carry Out Test Program***
- ***Use Production Pile & Driving Equipment***
- ***Measure Pile Head and Tip Movement***
- ***Load to Failure***
- ***Define Method to Interpret Failure Load***

Slide 9-3-35

SOILS AND FOUNDATIONS WORKSHOP

Static Load Test Factor of Safety

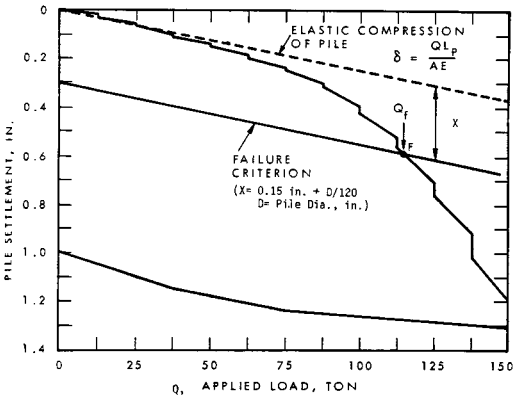
$$\textit{Safe Design Load} = \frac{\text{Load Test Failure Load}}{\text{F.S.} = 2}$$

- ***May Need F.S. > 2 When*** **Settlement May Control Safe Allowable Load**

Slide 9-3-36

SOILS AND FOUNDATIONS WORKSHOP

Interpretation of the Failure Load by Davisson's Limit

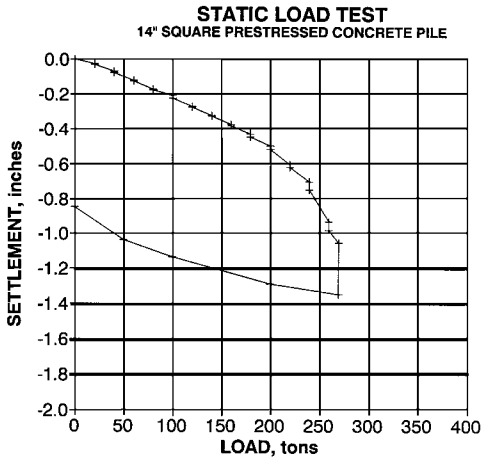


Slide 9-3-37

SOILS AND FOUNDATIONS WORKSHOP

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).



Slide 9-3-38

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

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

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	Stroke (ft) 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

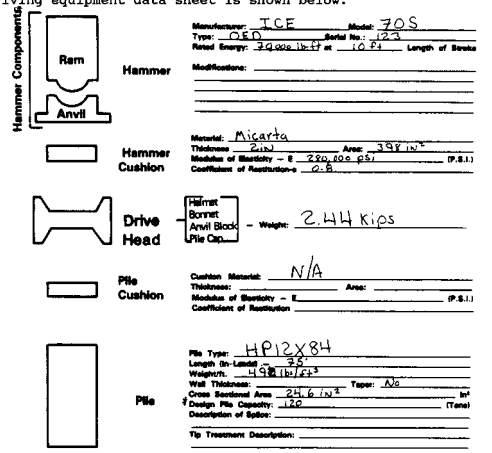
Slide 9-3-42

SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY
Construction Monitoring
Hammer Approval

ACCEPTANCE OF CONTRACTORS DRIVING SYSTEM

Contractor has submitted a ICE 70-S driving system. The pile and driving equipment data sheet is shown below.



Slide 9-3-43

SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY

ICE 70S HAMMER APPROVAL

WAVE EQUATION RESULTS OVER 75' DEPTH

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

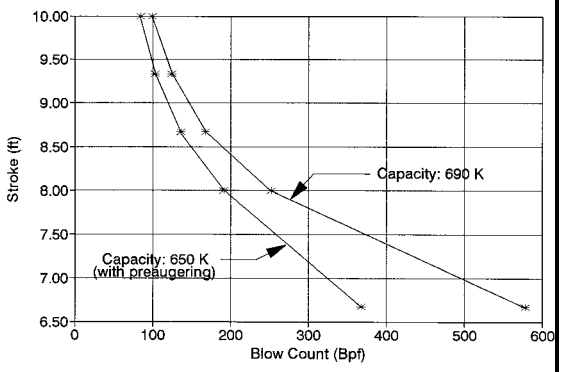
Slide 9-3-44

SOILS AND FOUNDATIONS WORKSHOP

APPLE FREEWAY PROBLEM

Construction Monitoring

Diesel Hammer Stroke vs. Blow Count @ 75'



Slide 9-3-45

SOILS AND FOUNDATIONS WORKSHOP

CONSTRUCTION ASPECTS

Pile Driveability

Driveability of 12 x 84 H-Pile Section verified for most difficult driving condition.

Driveability versus Depth

Driveability of 12 x 84 computed for full 75' depth.

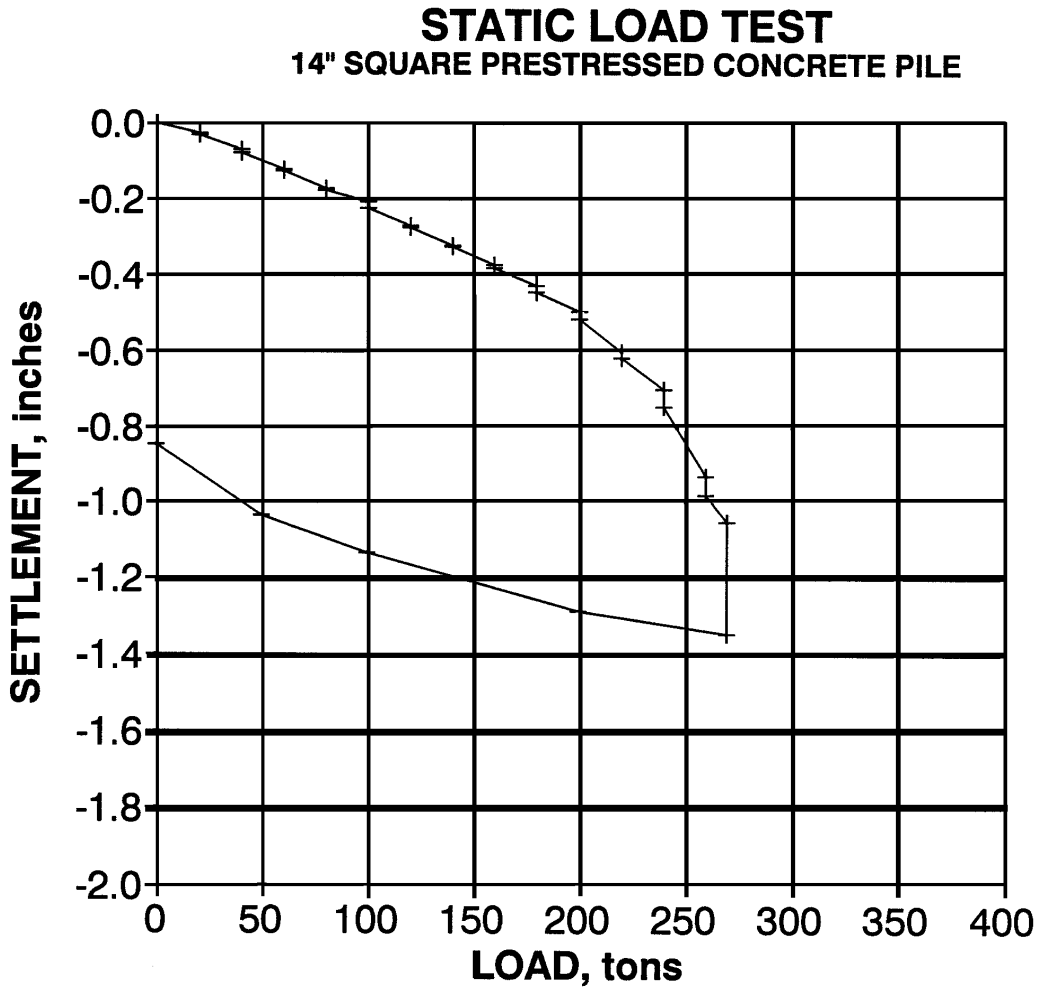
Pile installation time expected to vary between 16 and 20 minutes (no preaugering).

Slide 9-3-46

SOILS AND FOUNDATIONS WORKSHOP

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).



LESSON 10

Foundation Investigation Report

SOILS AND FOUNDATIONS WORKSHOP

FOUNDATION INVESTIGATION REPORT

Lesson 10

Slide 10-1

SOILS AND FOUNDATIONS WORKSHOP

FOUNDATION INVESTIGATION REPORT

1. Recall Contents of A Foundation Report

ACTIVITY: ***Question-Answer***

Slide 10-2

SOILS AND FOUNDATIONS WORKSHOP

Foundation Report

The Foundation Report is the Tool Used to Communicate the Site Conditions, and the Recommendations for Design and Construction to Bridge, Roadway, Construction, and Maintenance.

Slide 10-3

SOILS AND FOUNDATIONS WORKSHOP

Foundation Report

Often Referred to During Design, Construction, and After Project Completion (in Resolving Claims or Planning Maintenance Operations).

Slide 10-4

SOILS AND FOUNDATIONS WORKSHOP

Foundation Report

The Foundation Report Should be Clear, Concise and Accurate. The Preparation of this Document Deserves Special Care and Effort.

Slide 10-5

SOILS AND FOUNDATIONS WORKSHOP

Guidelines for Report Preparation

- ***Author has a Broad Engineering Background***
- ***Include Engineering Analysis and Interpretation***
- ***Include Definitive Recommendations***

Slide 10-6

SOILS AND FOUNDATIONS WORKSHOP

Guidelines for Report Preparation (Cont'd)

- ***Discuss Materials and Conditions Encountered in Construction***
- ***Anticipate Problems and List Solutions***

Slide 10-7

SOILS AND FOUNDATIONS WORKSHOP

Guidelines for Report Preparation (Cont'd)

- ***Be Concise and Definite; not Wishy-washy***
- ***Include Supporting Data and Special Notes***
- ***Omit Extraneous Data***

Slide 10-8

SOILS AND FOUNDATIONS WORKSHOP

General Outline of Report

- *Introduction*
- *Scope*
- *Date of Reference Plans*
- *Interpretation of Subsurface Conditions*

Slide 10-9

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

SOILS AND FOUNDATIONS WORKSHOP

Spread Footings

- ***Elevation***
- ***Dimensions***
- ***Allowable Bearing Value***
- ***Settlement***
- ***Remedial Measures and Costs***

Slide 10-13

SOILS AND FOUNDATIONS WORKSHOP

Piles

- ***Suitable Types***
- ***Tip Elevation***
- ***Load Capacity***
- ***Driving Criteria***
- ***Driveability***
- ***Load Tests***

Slide 10-14

SOILS AND FOUNDATIONS WORKSHOP

Drilled Shafts

- ***Diameter***
- ***Length***
- ***Load Capacity***
- ***Settlement***
- ***Constructibility***
- ***Load Tests***

Slide 10-15

SOILS AND FOUNDATIONS WORKSHOP

Construction

- ***Water Table***
- ***Pile Installation***
- ***Drilled Shaft Installation***
- ***Excavation Slopes***
- ***Effects on Adjacent Structures***

Slide 10-16

SOILS AND FOUNDATIONS WORKSHOP

Special Notes

Special Notes Should be Placed in the Plans or Special Provisions to Bring Attention to Certain Requirements of Design, Construction, or Anticipated Construction Problems.

Slide 10-17

SOILS AND FOUNDATIONS WORKSHOP

Typical Special Notes

Waiting Period

"A __ month waiting period will be imposed after completion of the embankment. The actual length of the waiting period may be reduced by the engineer based on analysis of instrumentation data."

Slide 10-18

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

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

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

SOILS AND FOUNDATIONS WORKSHOP

Subsurface Information Available to Bidders

- ***Bid Invitation Shows Where and When All Available Information may be Inspected***
- ***Agency Documents Contractor Inspection of Information***

Slide 10-22

SOILS AND FOUNDATIONS WORKSHOP

Disclaimers

General Disclaimer:

"Subsurface information was gathered for use in design. The contractor should not rely on such information in preparing the bid."

Slide 10-23

SOILS AND FOUNDATIONS WORKSHOP

Disclaimers (Cont'd)

- ***Courts Give Little Validity to General Disclaimers***
- ***Courts do Give Validity to specific Disclaimers***

Slide 10-24

SOILS AND FOUNDATIONS WORKSHOP

Specific Disclaimer

"The boring logs are representative of subsurface conditions at the site of the boring but conditions may vary between borings".

Slide 10-25

SOILS AND FOUNDATIONS WORKSHOP

Which Offices in the Highway Agency Routinely Receive Copies of a Foundation Investigation Report for a Bridge?

Slide 10-26

SOILS AND FOUNDATIONS WORKSHOP

Foundation Report Distribution

Copies to:

- ***Bridge Design***
- ***Roadway Design***
- ***Construction Section***
- ***Project Engineer File***
- ***Others Required by Agency Policy***

STUDENT

Take 10 Minutes to Read Foundation Report for Workshop Design Problem

Slide 10-27

SOILS AND FOUNDATIONS WORKSHOP

FOUNDATION INVESTIGATION REPORT

1. Recall Contents of A Foundation Report

ACTIVITY: ***Question-Answer***

Slide 10-28

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

LESSON 12

Solutions to Student Exercises

SOILS AND FOUNDATIONS WORKSHOP

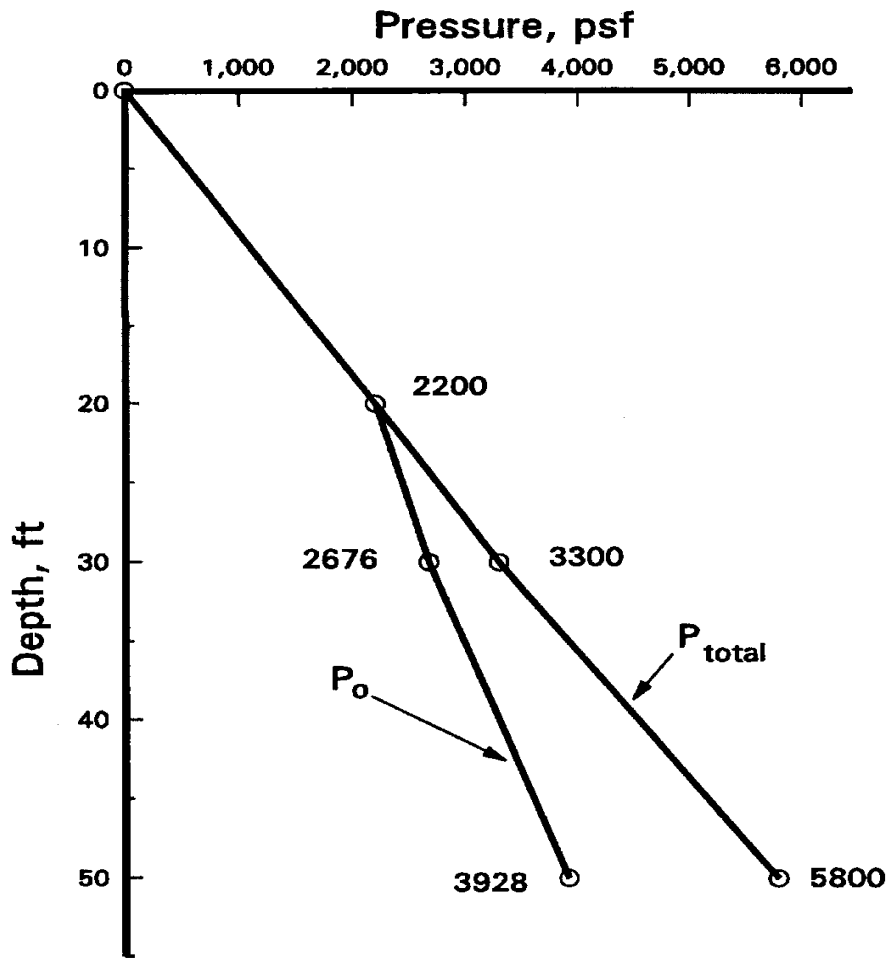
Solution to Exercise No. 1

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.**

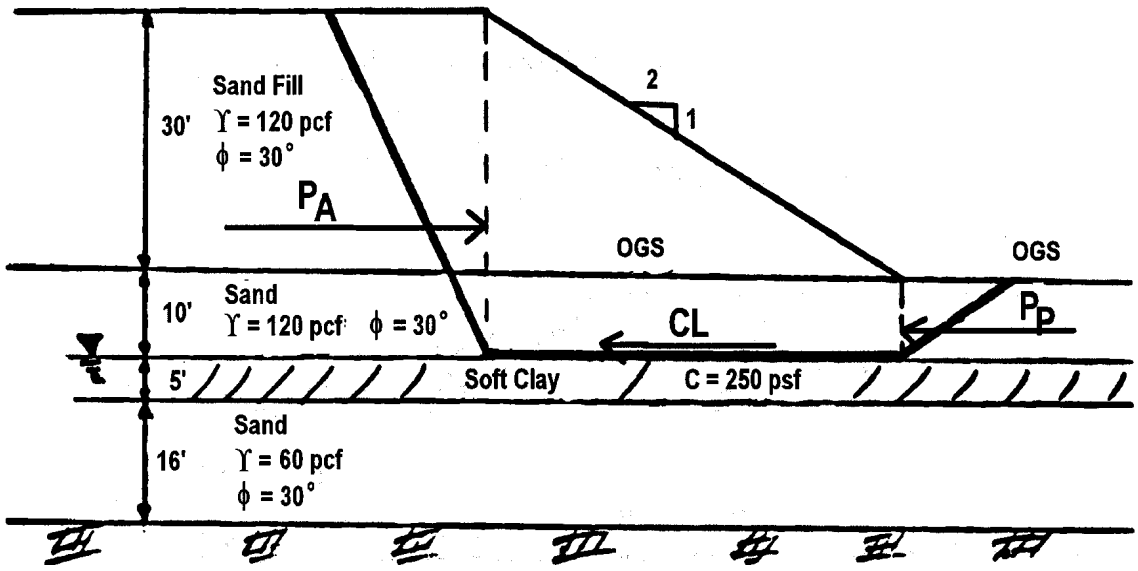
SOILS AND FOUNDATIONS WORKSHOP

Solution to Exercise No. 1 (Cont'd)



SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 2 - SOLUTION



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

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

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

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

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

Summing forces horizontally:

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

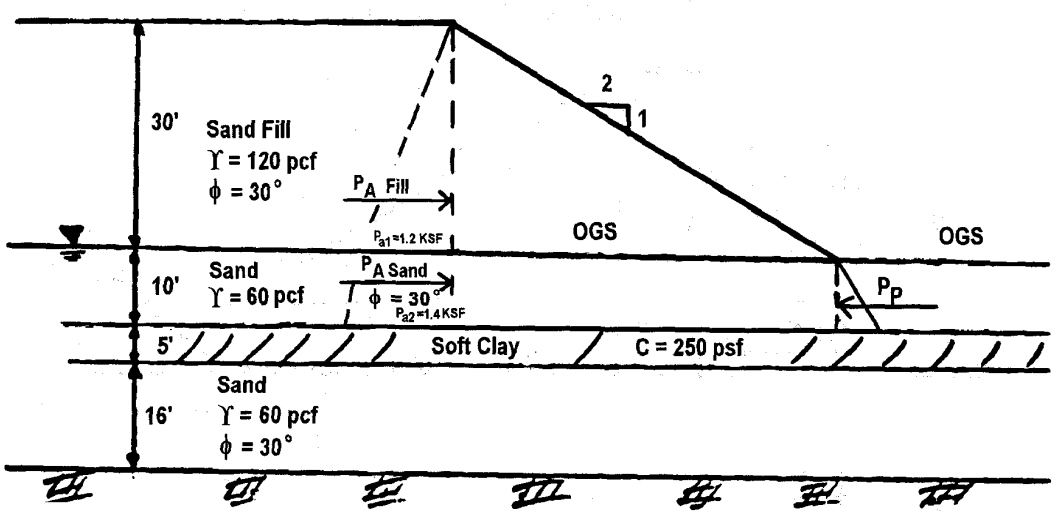
F.S. = 1.03 – TOO LOW!!

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.



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

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

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

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

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

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

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

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

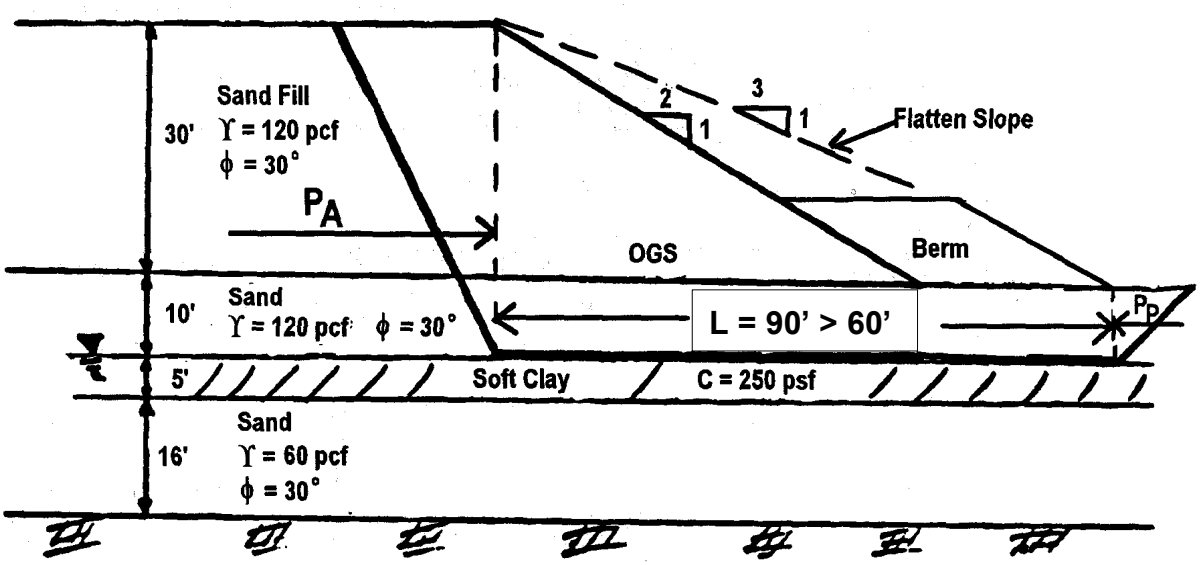
NOTE: 10' rise in water table lowers F.S. from 1.03 to 0.77

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

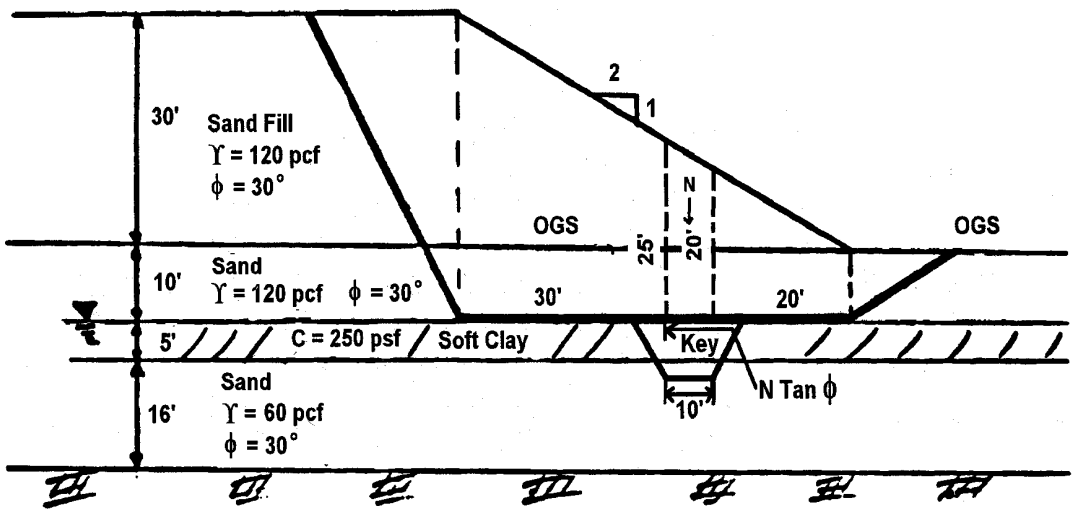
SOILS AND FOUNDATIONS WORKSHOP

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.

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

$$N\,Tan\phi = 27K(Tan30°) = 16K$$

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

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

OK

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

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.

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

SOILS AND FOUNDATIONS WORKSHOP

SOLUTION TO EXERCISE No. 5

Footing $\frac{Length}{Width} = \frac{50}{10} = 5 > 9$

$\therefore$ **Use Rectangular Formula**

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

$\therefore$ **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

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

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 6 SOLUTION
Footing Settlement

Sand Layer

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

5' – 15'

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

15' – 25'

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

Clay Layer

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

25' – 35'

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

35' – 45'

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

Total Footing Settlement (inches) = 3.6"

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.
$\delta/\phi = 0.77$
$\delta = (0.77)(30) = 23.1°$
$K_\delta = 1.15$
$C_F = 0.90$
$P_{0\ avg\ 27'} = 2230$

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 7 SOLUTION (cont'd)

$q_s = (1.15)(0.90)(2230)(\text{Sin } 23.1)(4)(30)$

$\underline{q_s = 54.3 \text{ tons}}$

END BEARING

a. $Q_p = A_P \; \alpha P_d N'_q$
$= (1)(0.5)(3000)(30)$
$Q_p = 22.5 \text{ tons}$

b. $Q_{lim} = (A_P)(q_{lim})$
$= (1)(6.5)$
$Q_{lim} = 6.5 \text{ tons}$

$\therefore \underline{Q_p = 6.5 \text{ tons}}$

$Q_{TOTAL} = 19 + 54.3 + 6.5$
$\underline{Q_T = 79.8 \text{ tons}}$

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

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 ✓

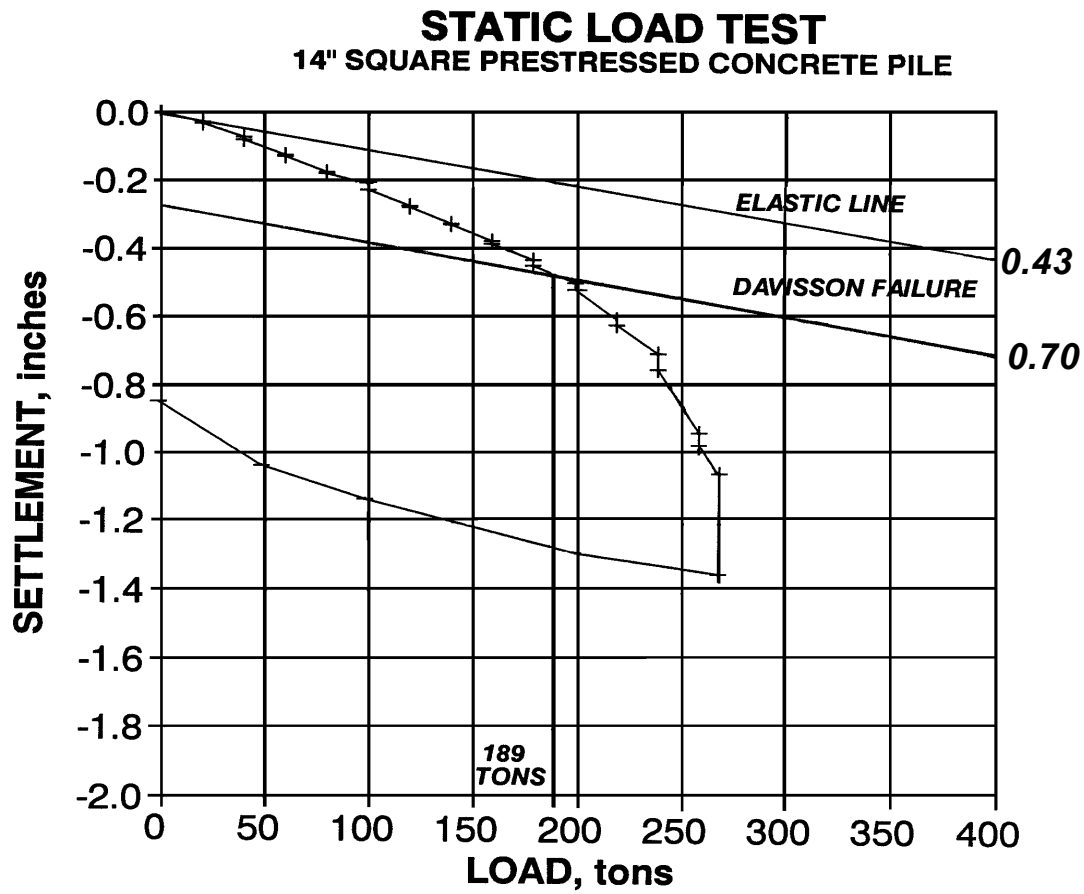
SOILS AND FOUNDATIONS WORKSHOP

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



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15. Supplementary Notes

FHWA Contracting Officer – Richard Murray/Dennis Luquette

FHWA COTR – L. Jones

FHWA Technical Review – J.A. DiMaggio, A. Muñoz, P. Osborn

16. Abstract

The Soils and Foundations Workshop is a basic geotechnical course (NHI Course No. 132012) 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 Participant Workbook includes copies of visual aids and student exercises that closely follow 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.

17. Key Words	18. Distribution Statement
Foundation design, site investigation, soil testing, spread footings, piles, wave equation	No restrictions.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
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