# DOCUMENT RESUME

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ABSTRACT

Described are lecture topics and laboratory assignments for a course offered to engineering technology students specializing in construction. A dual-purpose laboratory which serves both engineering technology students and civil engineering students is described. The course work may be presented during either a 10-week quarter or may be expanded for a semester course. (RE)

# COURSE PRESENTATION TEXT
# FOR
# FOUNDATIONS AND SOIL MECHANICS - ETC 411

by

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July, 1975

Report NSF/CP No. 1

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# INTRODUCTION STATEMENT

The text material that follows is the result of work accomplished by Dr. James Thompson under an NSF Grant GY-10474 for the development of a baccalaureate level engineering technology program.

This material covers in detail lecture topics and laboratory assignments for a Foundations and Soil Mechanics class offered to engineering technology students specializing in construction. It is designed to fit into a ten-week quarter, but could be expanded for a semester course.

In addition to text-material preparation, supplemental laboratory equipment was specified, ordered, and installed in the Soil Mechanics lab. This dual purpose lab will be used by engineering technology students specializing in construction as well as civil engineering students in their Soil Mechanics classes.

The NSF/Engineering Technology Grant was awarded with the understanding that reports developed for the Cal Poly Engineering Technology Department will also be available to other educational institutions offering both engineering and engineering technology programs. Consistent with this objective, we will be happy to transmit copies of this specialized report to any interested School of Engineering and/or Technology.

# CALIFORNIA STATE POLYTECHNIC UNIVERSITY - POMONA

## ENGINEERING TECHNOLOGY DEPARTMENT

## CONSTRUCTION

| FRESHMAN F | FRESHMAN W | FRESHMAN S | SOPHOMORE F | SOPHOMORE W | SOPHOMORE S | | JUNIOR F | JUNIOR W | JUNIOR S | | SENIOR F | SENIOR W | SENIOR S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ETC 101 CONSTRUCTION 3 | ETC 102 CONSTRUCTION DRAFTING 3 | ETC 111 CONSTRUCTION SURVEYING I 4 | ETC 112 CONSTRUCTION SURVEYING II 4 | | | | ETC 304 CONSTRUCTION ESTIMATING 4 | ETC 30[illegible] BUILDING ESTIMATING 3 | ETC 305 HEAVY ESTIMATING 3 | | ETC 404 CONSTRUCTION INSPECTION 3 | ETC 4[illegible] CONST[illegible] & COST CONTROL 3 | [illegible] 3 |
| ESG 121 Engr Drawing (Graphics) 2 | | | ETT 301 ENGINEERING MATERIALS 4 | ETT 210 APPLIED MECHANICS 4 | ETT 220 STRENGTH OF MATERIALS 4 | | ETC 311 STRUCTURAL THEORY 3 | ETC 315 CONCRETE & STEEL DESIGN 4 | ETC 31[illegible] TIMBER & FORMWORK DESIGN 4 | | ETC 411 [illegible] & SOIL MECH 4 | ETC 402 CONSTR[illegible] & SPECIFICATIONS 3 | ETC 41[illegible] [illegible] 3 |
| | | | ESG 125 DESCRIPTIVE GEOMETRY 2 | | ETP 279 ENGR. COST ACCOUNTING 3 | | ETC 301 CONSTRUCTION ECONOMY 3 | ETC 312 CONST EQUIP & METHODS 3 | ETC 270 ELECTRICAL INSTALLATIONS 4 | | ETT 234 Welding (Mat'l Join.) 2 | ETT 310 APPLIED FLUID MECH 4 | AE 299 CONSTRUCTION EQUIP OPERATION 4 |
| | | | | | | | ETC 431 CONCRETE MIX DESIGN 2 | ETC 432 BITUMINOUS PAVEMENT DESIGN 3 | | | ETT 461 SENIOR PROJECT 2 | ETT 462 SENIOR PROJECT 2 | ETT 463 INTEGRATED SEMINAR 2 |
| | | | | | | ETT 370 CONSTRUCTION INTERNSHIP 4 | | | | ETT 470 CONSTRUCTION INTERNSHIP 4 | | | |
| MAT 104 TRIGONOMETRY 4 | MAT 105 COLLEGE ALGEBRA 4 | MAT 108 INTRO MATH ANALYSIS I 3 | MAT 109 INTRO MATH ANALYSIS II 3 | ETT 110 COMPUTER APPLICATION 4 | | | | MATH ELECTIVE 4 | | | | | |
| ELECTIVE 3 | CHM 104 & 141 COLLEGE CHEMISTRY 4 | PHY 121 COLLEGE PHYSICS 4 | PHY 122 COLLEGE PHYSICS 4 | PHY 123 COLLEGE PHYSICS 4 | BIO 110 LIFE SCIENCE 3 | | ESC 321 ENGINEERING GEOLOGY 4 | | | | | | |
| ENG 104 FRESHMAN COMPOSITION 4 | AHC 201 Am Civ (Govt) 4 | AHC 202 Am Civ (U.S. History) 4 | | | | | | | | | | | PSY 332 [illegible] & PERS. PSYCHOLOGY 4 |
| PE 141 PHYSICAL EDUCATION 1 | PE 141 PHYSICAL EDUCATION 1 | PE 141 PHYSICAL EDUCATION 1 | | EC 201 ECONOMICS 4 | COM 219 TECHNICAL WRITING 4 | | | | COMMUNICATION ARTS ELECTIVE 4 | | HUMANITIES ELECTIVES 4 | HUMANITIES ELECTIVES 4 | |
| 17 | 16 | 16 | 17 | 16 | 14 | 4 | 16 | 17 | 15 | 4 | 15 | 16 | 15 |

CALIFORNIA STATE POLYTECHNIC UNIVERSITY,
POMONA
Pomona, California

Course Title: Foundations & Soil Mechanics
Date of Outline Preparation: December 9, 1973
Prepared By: James B. Thompson

## COURSE OUTLINE

## Engineering Technology Department

I. Catalog Description

ETC 411 Foundations and Soil Mechanics (4)

Selection and methods of installation of foundations and other soil supported structures. Footings, piles, caissons, retaining structures, soil embankments and fills. 3 lectures, 1 three-hour laboratory.

II. Required Background of Experience

ESC 321 Recommended

II. Detailed Description of the Course

A. Expanded Description of the Course

1. Composition of soil
2. Soil classification
3. Properties and characteristics of soil and their determination
   - a. Specific gravity
   - b. Grain size distribution
   - c. Water content
   - d. Atterberg limits and indices
   - e. Permeability
   - f. Compaction characteristics
   - g. Consolidation characteristics
   - h. Stress-strain and strength characteristics
4. Field Investigations
5. Design and Construction problems dealing with soil
   - a. Engineered fills
   - b. Seepage through soils
   - c. Retaining structures
   - d. Foundations
   - e. Soil slopes
   - f. Earth and rock fill dams
   - g. Subgrades
6. Laboratory Testing
   - a. Atterberg limits and indices
   - b. Grain size analysis
   - c. Permeability test
   - d. Compaction test
   - e. Field density tests
   - f. Field investigation
   - g. Consolidation Test
   - h. Direct shear test
   - i. Unconfined compression test
   - j. Relative density test
   - k. Earthquake simulation testing

B. Methods of Instruction and Evaluation

1. Instruction

Lectures: 3 one-hour lectures per week

Laboratory: 1 three-hour laboratory per week

2. Evaluation

Lectures: (a) Periodic exams
(b) Final exam
(c) Homework

Laboratory: Laboratory reports

C. Expected Outcome

Adequate understanding for soil to work in the field of soil mechanics and foundation engineering as a construction engineer, an inspector, or as a technician.

C. Minimum Student Materials

Assigned texts, log-log slide rule, engineering computation paper, graph paper, pencil, pen and straight edge.

E. Minimum College Facilities

Standard university lecture room equipped with chalkboard.

Soil mechanics laboratory equipped for making the following tests on soils: Atterberg Limits and Indices Test, Grain Size Analysis Test, Permeability Test, Compaction Test, Field Density Tests, Field Investigation, Consolidation Test, Direct Shear Test, Unconfined Compression Test, Relative Density Test, and Earthquake Simulation Tests.

IV. Texts and References

Texts: Hough, B. K., Basic Soils Engineering, Ronald Press Company, New York, 1969

Lambe, T. William, Soil Testing for Engineers, John Wiley & Sons, Inc., New York, 1951

References: Materials available in the University Library.

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

## ETC 411 - FOUNDATIONS AND SOIL MECHANICS

Tentative Lecture Schedule

Instructor: J. B. Thompson

Spring Quarter, 1975

Text: Hough, B. K., Basic Soils Engineering
Ronald Press Company, New York, 1969

| WEEK | DATE | MAJOR SUBJECT(S) | ASSIGNMENT | |
|---|---|---|---|---|
| | | | READING | PROBLEMS |
| 1 | | Introduction, Soil Composition, Soil Phase Relationships | pp.3-13, 28-47 | 2-22, 2-28, 2-31 2-34, 2-42, 2-44 |
| 2. | | Grain Size Analysis, Atterberg Limits & Indices | pp.13-28, 47-52, 90-104 | 2-10, 2-11, 2-55 2-62 |
| 3 | | Soil Classification | pp.470-478 602-605 | Handout |
| 4 | | Soil Specific Gravity and Permeability | pp.72-78 | 3-28, 3-31 Handout |
| 5 | | Soil Compaction, Geostatic Stress in Soil | pp.199-205, 505-517 | 7-1, 7-2, 7-7, 13-2, 13-3 |
| 6 | | Soil Consolidation and Stress-Strain and Strength Characteristics | pp.106-158 | Handout |
| 7 | | Soil Stress-Strain and Strength Characteristics | pp.163-196, 223-233 | Handout |
| 8 | | Field Investigations, Engineered Fills, Seepage Through Soils | pp.59-72, 78-86,492-505, 517-527, 529-570, 606-616 | Handout |
| 9 | | Retaining Structures, Foundations | pp.205-222, 233-250,296-465, 568-601 [Brief parts] | Handout |
| 10 | | Soil Slopes, Soil & Rock Fill Dams, Subgrades, Course Review and Summary | pp.255-293, 468-470, 479-490 | Handout |

Course Grading:

| | |
|---|---|
| Laboratory | 30% |
| Homework | 20% |
| Hour Exam | 20% |
| Final Exam | 30% |
| Total | 100% |

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411 Outline of Weekly Lecture Notes Prepared By: J.B.Thompson

Week No: 1 Date: 11/5/73

Lecture Subjects: Introduction, Soil Composition, Soil Phase Relationships

Assignment: Read - pp. 3-13, 28-47

Problems - 2-22, 2-28, 2-31, 2-34, 2-42, 2-44

Presentation

I. Check Roll

II. Discuss Course Lecture Schedule

A. Text
B. Grade Evaluation
1. Course Grading:
Laboratory - 30%
Homework - 20%
Hour Exam - 20%
Final Exam - 30%
100%

2. Homework Policy:
a. Approximately one homework set per week.
b. Each homework set normally due one week after assigned.
c. Late homework will receive 1/2 credit.
d. No homework will be accepted after returning the corrected papers.
e. Correct homework problem solutions will be posted.

C. Scope of the Course

1. Composition of soil
2. Soil Classification
3. Properties of soil and their determination
4. Field investigations
5. Design and construction problems dealing with soil (Emphasize Construction Problems)
a. Engineered Fills
b. Seepage through soils
c. Retaining structures
d. Foundations
e. Soil Slopes
f. Earth and rock fill dams
g. Subgrades

III. Historical Review of Soil Mechanics and Foundation Engineering

A. Modern-Day techniques are relatively new

B. Early methods

1. Trial and error
2. Difficulties and limitations

C. Improved understanding for material behavior

D. Development of Quasi-Theoretical solutions and empirical relationships

E. Present day practice

1. Theoretical and empirical solutions
2. Experience
3. Continuing development in the profession
  a. Improved solutions to existing problems
  b. New problems

IV. General Areas of Involvement

A. Structural Foundations

B. Pavements

C. Earthworks

V. Soil Composition

A. Three Phase Material

B. Solids

1. Discrete solid particles or grains
  a. Variable size
  b. Variable composition
  c. Examples: Boulders, sand grains, clay minerals

2. Organic materials
  a. Examples: Fibers, roots, shells

3. Cementing Agents
  a. Examples: Silica, clay

C. Liquids

1. Examples: Pure water, salt water, organic acids (humic acid)

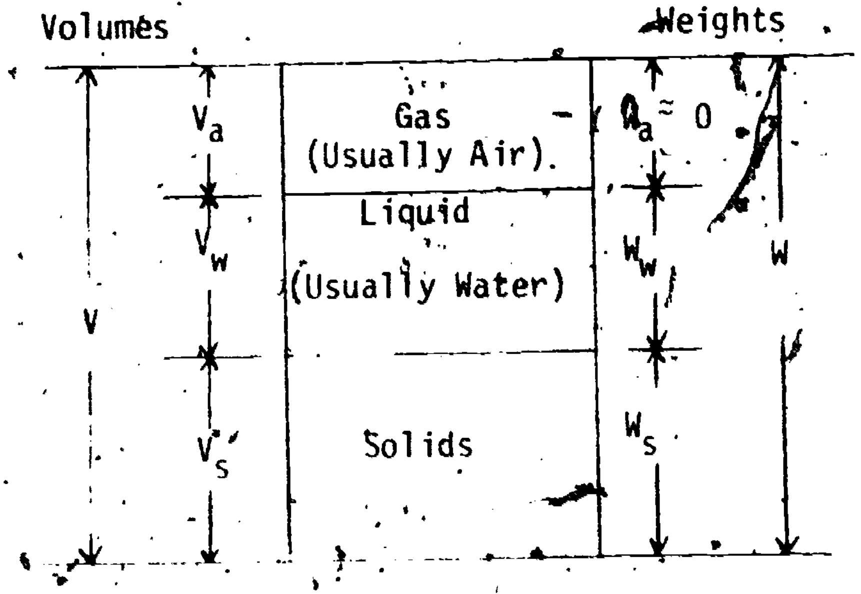
D. Gases

1. Examples: Air, hydrogen sulfide, methane

## VI. Weight-Volume Relationships

A. Expressions for relative amounts of solids, liquids, and gases present

B. Block diagram (visualization)



where: V - Total volume
$V_a$ - Volume of the gases
$V_w$ - Volume of the liquids
$V_s$ - Volume of the solids

W - Total weight
$W_a$ - Weight of the gases
$W_w$ - Weight of the liquids
$W_s$ - Weight of the solids

$V = V_a + V_w + V_s$

$W = W_a + W_w + W_s$

C. Porosity

1. Ratio of the volume of the voids ($V_v = V_a + V_w$) to the total soil volume (V) times 100%.

2. Porosity = $n = \frac{(V_a + V_w)}{(V)} \times 100\% = \frac{V_v}{V} \times 100\%$ (no units)

D. Void Ratio

1. Ratio of the volume of the voids ($V_v = V_a + V_w$) to the volume of the solids ($V_s$).

2. Void ratio = $e = \frac{V_v}{V_s}$ (no units)

E. Water Content

1. Ratio of the weight of the water in the soil ($W_w$) to the weight of the solids ($W_s$) times 100%.

2. Water content = $w = \frac{W_w}{W_s} \times 100\%$ (no units)

3. Laboratory water content determination procedure
   - a. Weigh wet soil - $W$
   - b. Oven dry soil @ 110°C
   - c. Weigh dry soil - $W_s$
   - d. Compute weight of water = $W_w = W - W_s$
   - e. Compute water content = $w = W_w/W_s \times 100\%$

F. Degree of Saturation

1. Ratio of the volume of the water in the soil ($V_w$) to the volume of the voids ($V_v = V_a + V_w$) times 100%

2. Degree of saturation = $S_r = \dfrac{V_w}{V_v} \times 100\%$ (no units)

G. Bulk Density

1. Ratio of the total weight of the soil (W) to the total volume of the soil (V)

2. Bulk density = $\gamma = W/V$ (pcf, tcf, gm/cc.)

H. Dry Density

1. Ratio of the weight of the soil solids ($W_s$) to the total volume of the soil (V)

2. Dry Density = $\gamma_d = \dfrac{W_s}{V}$ (pcf, tcf, gm/cc.)

I. Saturated Density

1. Ratio of the total weight of the soil (W) to its total volume (V) if the soil were completely saturated ($S_r = 100\%$) while retaining its original volume.

2. Saturated Density = $\gamma_{sat} = \dfrac{W^*}{V}$ (pcf, tcf, gm/cc.)

   Where: $W^*$ = total soil weight corresponding to a completely saturated soil ($S_r = 100\%$)

J. Buoyant Density

1. Difference between the bulk density of the soil ($\gamma$) and the density of water ($\gamma_w$) both expressed in the same units.

2. Buoyant density = $\gamma_b = \gamma - \gamma_w$ (pcf, tcf, gm/cc.)

3. Density of water
   - a. For pure water: $\gamma_w = 62.4$ pcf = 1gm/cc.
   - b. For salt water: $\gamma_w > 62.4$ pcf

K. Density of the Soil Solids

1. Ratio of the weight of the solids ($W_s$) to the volume of the solids ($V_s$)

2. Density of the soil solids = $\gamma_s = \dfrac{W_s}{V_s}$ (pcf, tcf, gm/cc.)

L. Specific Gravity of the Soil

1. Ratio of the density of the soil solids ($\gamma_s$) to the density of water ($\gamma_w$)

2. Specific Gravity = $G_s = \gamma_s/\gamma_w$ (no units)

3. Typical range for soils: $G_s = 2.6 - 2.8$

M. Relative Density

1. Ratio of the difference between the maximum void ratio of the soil ($e_{max}$) and the existing soil void ratio (e) to the difference between the maximum void ratio of the soil ($e_{max}$) and the minimum soil void ratio ($e_{min}$) times 100%.

2. Relative Density = $D_R = \dfrac{e_{max}-e}{e_{max}-e_{min}} \times 100\%$

3. Applied to the description of granular soils

   a. $D_r < 50\%$: Soil is loose
   b. $D_R > 50\%$: Soil is dense

N. Example Problems

1. Example Problem #1
   a. Given: $n = 0.4$
   b. Find: e

2. Example Problem #2
   a. Given: $W_s = 100$ lbs.
      $V = 1$ cu.ft.
      $G_s = 2.65$
      $\gamma_w = 62.4$ pcf
   b. Find: e

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411 Outline of Weekly Lecture Notes Prepared by: J.B. Thompson

Week No: 2 Date: November 5, 1973

Lecture Subjects: Grain Size Analysis, Atterberg Limits and Indices

Assignment: Read - 13-28, 47-52, 90-104

Problems - 2-10, 2-11, 2-55, 2-62

## Presentation

I. Grain Size Analysis

A. Description of a soil in terms of its particle size composition

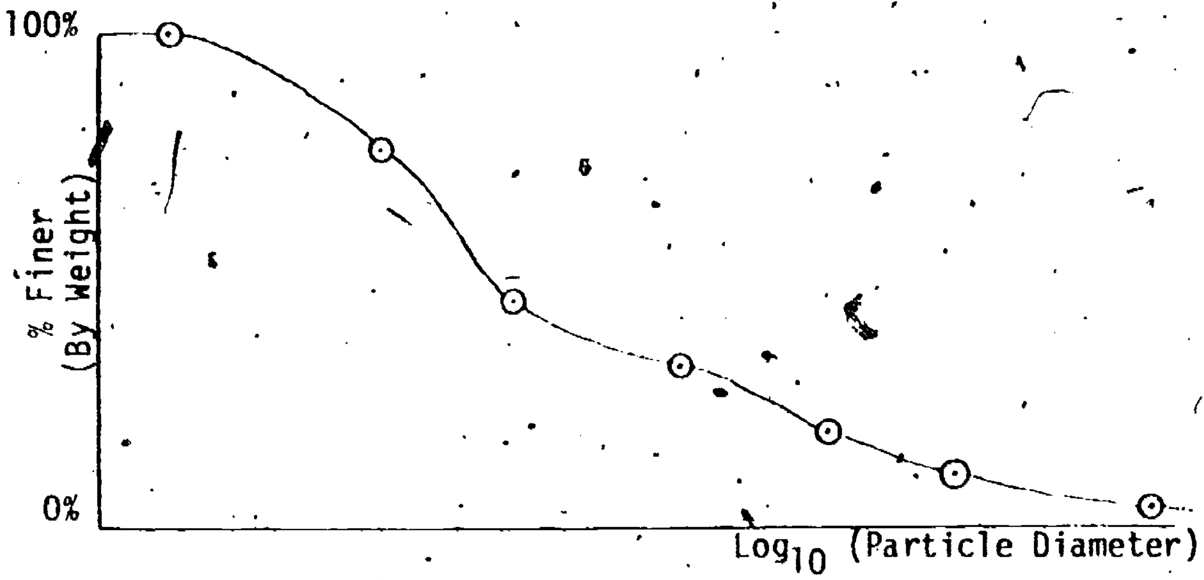
B. Utilization

1. Soil classification (will be discussed first in this course)
2. Fill design and construction
3. F[illegible] design and construction

C. Grai[illegible]istribution Curve

1. Standard plot representing the sizes and relative amounts of the particles comprising the soil

2.



3. Tests performed for plotting the grain size distribution curve

a. Direct measurement
  i. Particles larger than gravel

b. Sieve analysis
  i. Particles smaller than gravel and larger than course silts
  ii. Procedure description

c. Hydrometer analysis
   - i. Particles smaller than fine sands and larger than colloidal sizes
   - ii. Based on Stokes Law and fluid density determinations made with an hydrometer
   - iii. Brief explanation of theory
   - iv. Presentation of equations utilized in data reduction
   - v. Procedure description

d. Combined analysis
   - i. Utilize two or more of the above tests if necessary

4. Example Problem

a. Given: i. Total soil specimen weight = 200 gms
   ii. Sieve analysis data

| Sieve No. | Weight of Soil Retained (gms) |
|---|---|
| 4 | 0 |
| 8 | 5 |
| 20 | 65 |
| 40 | 50 |
| 100 | 40 |
| 200 | 28 |
| Pan | 12 |

   iii. Hydrometer analysis data (run on pan material)

| Particle Diameter (mm.) | % Finer By Weight |
|---|---|
| 0.05 | 3 |
| 0.01 | 2 |
| 0.005 | 1 |

b. Find: Grain size distribution curve

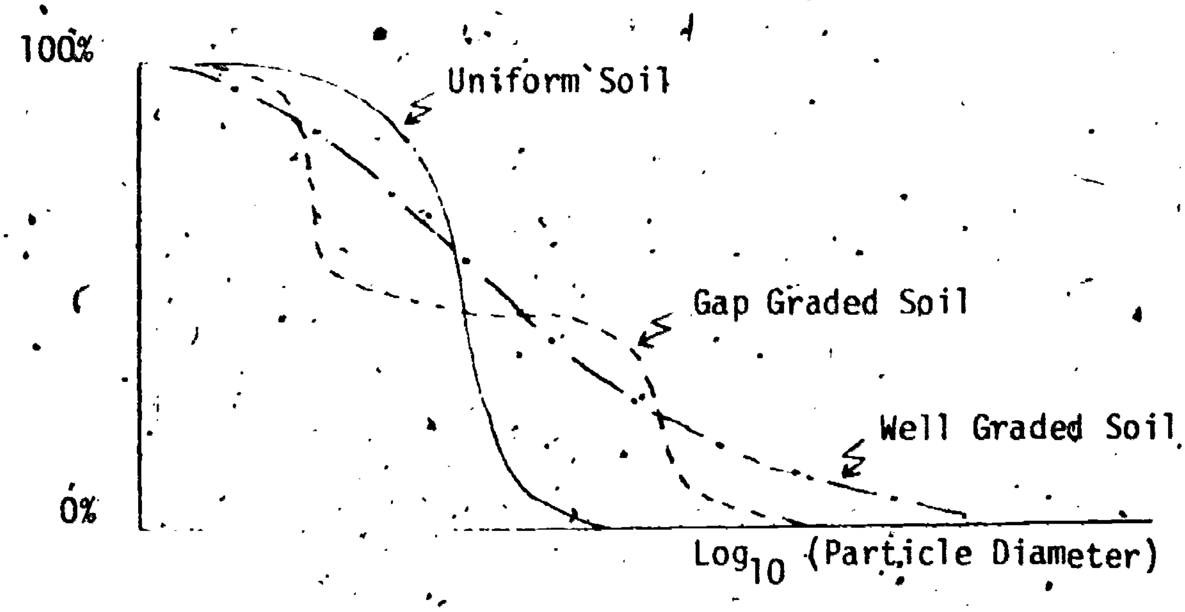
5. Soil Gradation Descriptions

a. Poorly graded or uniform soil - soil is composed of a limited range in particle sizes

b. Well graded soil - soil is composed of a wide range in particle-sizes

c. Gap graded soil - soil is composed of two or more limited ranges of particle sizes

d. Illustration - grain size distribution curve



e. Coefficient of uniformity
   i. Coefficient of uniformity = $C_u = D_{60}/D_{10}$
   ii. $D_{60}$ is the particle diameter below which 60% of the soil is finer
   iii. $D_{10}$ is the particle diameter below which 10% of the soil is finer
   iv. Cu<4: Soil is poorly graded
   v. Cu>6: Soil is well graded if the grain size distribution curve is smooth and reasonably symmetrical

6. Textural Classification Systems

   a. Based on grain size distribution
   b. Systems

| Soil Description | Particle Size Range (mm) | |
|---|---|---|
| | ASTM System | MIT System |
| Gravel | >4.76 | >2.0 |
| Course Sand | 4.76 - 2.0 | 2.0 - 0.6 |
| Medium Sand | 2.0 - 0.42 | 0.6 - 0.2 |
| Fine Sand | 0.42 - 0.074 | 0.2 - 0.06 |
| Silt | 0.074 - 0.002 | 0.06 - 0.002 |
| Clay | <0.002 | <0.002 |

   c. Classification of multi-sized soils

   d. Limitations
      i. Systems not indicative of composition of soil solids
      ii. Composition of solids particularly significant for fine grained soils

II. Atterberg Limits and Indices

A. Empirical limits and indices indicative of the composition of the solids in fine grained soil.

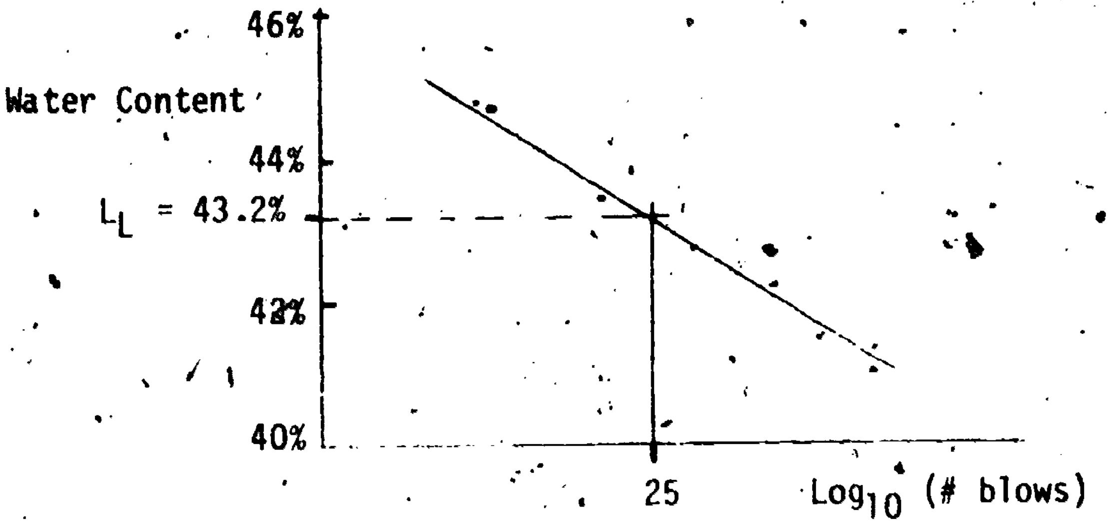
B. Utilization

   1. Soil classification (will be discussed first in this course)
   2. Empirical relationships for other soil characteristics

C. The Atterberg limits and the methods of determination

1. Liquid Limit (LL)

   a. The liquid limit (LL) of a soil is the water content at which a closure of 1/2" occurs in a standard groove cut in a pat of the soil after 25 standard blows are applied to the soil pat.
   b. Description of equipment
   c. Description of the testing procedure
   d. Interpretation of experimental data



2. Plastic Limit (PL)

   a. The plastic limit (PL) of a soil is the water content which will permit rolling a thread of the soil to a diameter of 1/8" and no smaller without crumbling.
   b. Description of equipment
   c. Description of the testing procedure

3. Shrinkage Limit (SL)

   a. Not commonly used.

D. Atterberg Indices

1. Plasticity Index (PI)

   a. Plasticity Index = PI = (LL-PL)
   b. Indicates the range over which the soil remains plastic

2. Liquidity Index (LI)

   a. Liquidity Index = $LI = \frac{w - PL}{LL - PL} = \frac{w - PL}{PI}$ where: w - soil natural water content
   b. Indicates at which end of the plasticity range the soil exists in nature
   c. A low liquidity index indicates a relatively strong, stiff soil.
   d. A high liquidity index indicates a relatively soft, weak soil

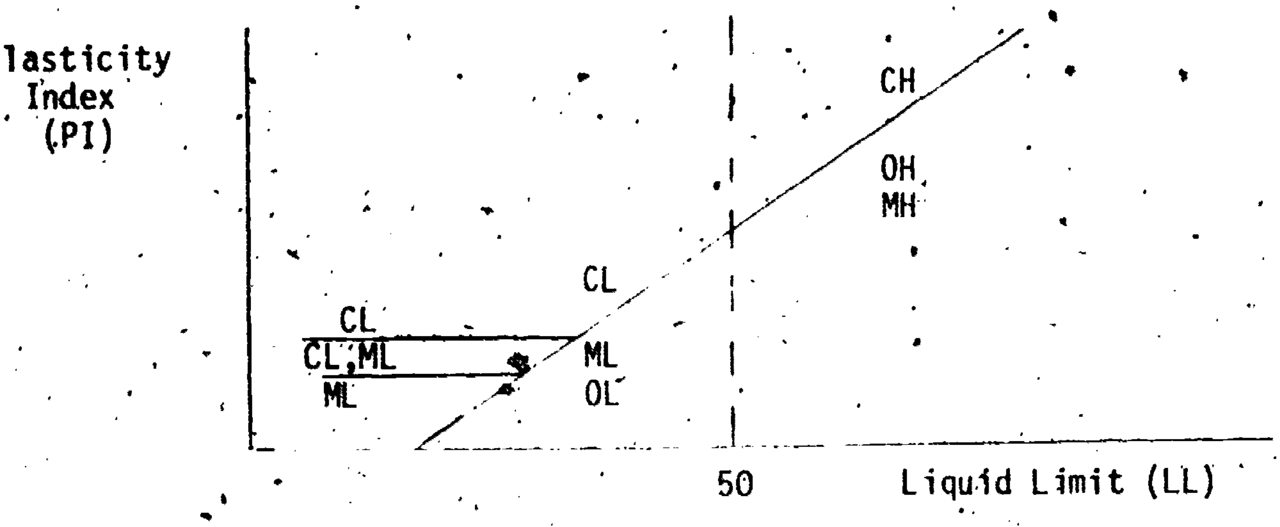
E. Explanation of the Basis for the Atterberg Limits and Indices Tests

1. Interaction of pore water and various different soil soils particularly in fined grined soils

F. Example Application of the Atterberg Limits and Indices

1. Soil classification system for fine grained soils developed by A. Cassagrande

2.



3. Plot Plasticity Index versus Liquid Limit for the soil to be classified and read the classification from the graph.

4. Plot to be discussed in more detail below

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411

Week No: 3

Outline of Weekly Lecture Notes

Prepared By: J.B. Thompson

Date: 11/5/73

Lecture Subjects: Soil Classification

Assignment: Read - 470-478, 602-605

Problems - To be assigned

Presentation

I. Major Soil Classification Systems

- A. Detailed classification systems developed for particular applications
- B. Pedological classification system
  1. Developed primarily for agricultural (Soil Science/Agronomy) purposes
  2. Bases:
     - a. Characteristics of parent material
     - b. Drainage conditions which existed during soil formation
     - c. Environmental conditions which existed during soil formation
     - d. Extent to which soil formation has occurred
  3. Importance to civil engineering
     - a. Basis of extensive surficial soils maps developed by the U. S. Department of Agriculture
     - b. Limited applications for the above maps (e.g. preliminary layout of highways)
- C. Revised Bureau of Public Roads, Highway Research Board, or AASHO Classification System
  1. Developed primarily for road construction (e.g. subgrades and embankments)
  2. Experimental tests needed to make a classification
     - a. Grain size analysis
     - b. Atterberg limits and indices
  3. Contents of a typical classification
     - a. Soil description
     - b. Group number
     - c. Group index
     - d. Subgrade rating
  4. Additional correlations between the classification and the behavior of a soil

5. Laboratory classification procedure

    a. Organic soil (Group A-8)
        i. Identified by color, odor, spongy feel and by fibrous texture in some cases

    b. All other soils (Groups A-1 through A-7)
        i. Process of elimination
        ii. Utilize the grain size analysis data to identify which possible group numbers the soil might fall under
        iii. Complete the identification of the group and subgroup number using the Atterberg Limits and Indices of the soil
        iv. Compute the Group Index (GI) for the soil

$$\text{Group Index} = GI = 0.2a + 0.005ac + 0.01bd$$

where:

a - % passing the No. 200 sieve greater than 35 and not exceeding 75 expressed as a whole number (value = 0 to 40)
b - % passing the No. 200 sieve greater than 15 and not exceeding 55 expressed as a whole number (value = 0 to 40)
c - That portion of the liquid limit greater than 40 and not exceeding 60 expressed as a whole number (value = 0 to 20)
d - That portion of the plasticity index greater than 10 and not exceeding 30, expressed as a whole number (value = 0 to 20)

Note: The Group Index is always expressed as a whole number

        v. Determine the subgrade rating of the soil and any other correlated behavioral characteristics of the soil needed
        vi. Provide a soil description

6. Typical classification

Description: High Compressibility Silty Clay
Subgrade Rating: Fair to Poor
Subgroup and Group Index: A-7-5 (17)

$\uparrow$ Group Index

Note: Frequently only the group number is presented and the subgroup number is omitted.

7. General observations

8. Example problem

    a. Given:
        i. % passing the No. 40 sieve = 95%
        ii. % passing the No. 200 sieve = 57%
        iii. LL of the minus No. 40 fraction = 37
        iv. PI of the minus No. 40 fraction = 18
        v. Soil is not organic

    b. Find: The Revised Bureau of Public Roads classification for this soil

D. Civil Aeronautics System (CAA)

1. Developed primarily for airfield construction (e.g. subgrades)

2. Experimental tests needed to make a classification

   a. Grain size analysis
   b. Atterberg Limits and Indices

3. Entire system very similar to the Revised Bureau of Public Roads System

4. Utilizes Group Numbers from E-1 through E-14

E. State Highway Department Classification Systems

1. Developed primarily for road construction (e.g. subgrades and embankments)

2. Specialized for soils encountered in a particular state

3. Frequently similar to the Revised Bureau of Public Roads System

F. Unified Soil Classification System

1. Successfully applied to many types of civil engineering projects

2. Probably the most popular classification system

3. Experimental tests needed to make a classification

   a. Grain size analysis
   b. Atterberg Limits and Indices

4. Contents of a typical classification

   a. Soil description
   b. Soil Group Symbol

5. Additional correlations between the classification and the behavior of a soil

6. Classification procedure

   a. Highly Organic Soil (Pt)
      i. Identified by color, odor, spongy feel and by fibrous texture in some cases

   b. All other soils (GW, GP, GM, GC, SW, SP, SM, SC, CL, ML, OL, CH, MH, OH)
      i. Process of elimination
      ii. Illustrate by working through chart

7. Explanation of Group Symbols

   a. Course grained soil

i. GW
ii. GP
iii. GM
iv. GC
v. SW
vi. SP
vii. SC
viii. SM

G - gravel } % finer No. 7 sieve
S - and

W - well graded } grading equations
P - uniform

M - silt, silty } amount and plasticity of fines
C - clay, clayey

b. Fine grained soils

i. ML
ii. CL
iii. OL
iv. MH
v. CH
vi. OH

M - silt } plasticity chart
C - clay
O - organic

L - low to medium plasticity } plasticity chart
H - medium to high plasticity

c. Highly organic soils:

i. Pt

8. Field classification techniques

9. Example problem

a. Given:

i. Grain size analysis data

| Sieve No. | % Finer |
|---|---|
| 10 | 100 |
| 20 | 86 |
| 40 | 72 |
| 60 | 60 |
| 100 | 45 |
| 200 | 35 |

ii. Atterberg Limits and Indices of minus no. 40 fraction

Liquid Limit (LL) = 19
Plasticity Index (PI) = 0

iii. Soil is not organic

b. Find: The Unified Soil Classification System classification for this soil

G. Comments on the classification systems used by various governmental and private civil engineering organizations.

## CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

## CIVIL ENGINEERING DEPARTMENT

Course: ETC 411

Prepared By: J.B.Thompson

### Outline of Weekly Lecture Notes

Week No: 4

Date: 11/5/73

Lecture Subjects: Soil Specific Gravity and Permeability

Assignment: Read - pp. 72-78

Problems - 3-28, 3-31, additional problems to be assigned

### Presentation

I. Principle Soil Properties and Characteristics and Their Determination

- A. Soil properties and characteristics are required in addition to a classification in order to predict and evaluate the behavior of the soil
- B. Principle soil properties and characteristics include:
    1. Specific gravity, $G_s$
    2. Grain size distribution
    3. Water content, w
    4. Atterberg Limits and Indices
    5. Permeability, k
    6. Compaction characteristics
    7. Consolidation characteristics
    8. Stress-strain and strength characteristics
- C. Specific gravity, $G_s$
    1. Definition
        - a. See previous discussion
        - b. $G_s = \gamma_s / \gamma_w$
    2. Utilization
        - a. Weight-volume calculations
    3. Methods of determination
        - a. Water displacement
            - i. measure volume of water (V') displaced by a certain weight of soil solids ($W_s$)
            - ii. Volume of solids = $V_s = V'$
            - iii. $\gamma_s = W_s/V_s = W_s/V'$
            - iv. $G_s = \gamma_s/\gamma_w = (W_s/V')/\gamma_w$
            - v. Example calculation
        - b. Air Pycnometer

   4. Typical soil values: $G_s \doteq 2.6$ to 2.8

D. Grain size distribution

   1. Discussed previously: Review briefly

E. Water content, w

   1. Discussed previously: Review briefly

F. Atterberg Limits and Indices

   1. Discussed previously: Review briefly

G. Soil permeability, k

   1. Definition

      a. Soil property which describes the rate at which water will flow through soil

   2. Utilization

      a. All problems in which the rate of flow of water through the soil is to be determined
      b. Examples
         i. Dewatering excavations
         ii. Seepage losses from reservoirs
         iii. Well capacity

   3. Darcy's Law

      a. Basic law which describes flow of water through soil
      b. Equations:

$$v = ki \qquad\qquad Q = kiA$$

$$Q = vA \text{ (continuity)}$$

where: v - velocity of flow of water through the soil (fps, cm/sec.)
Q - volumetric flow rate of water through the soil (cfs, cc/sec.)
k - soil permeability (fps, cm/sec.)
i - $\frac{\Delta h}{L}$ - hydraulic gradient (no units)
$\Delta h$ - head loss in the water over some length, L (ft, cm)
L - the length over which the head loss occurs (ft, cm)
A - crossectional area through which flow occurs ($ft.^2$, $cm^2$)

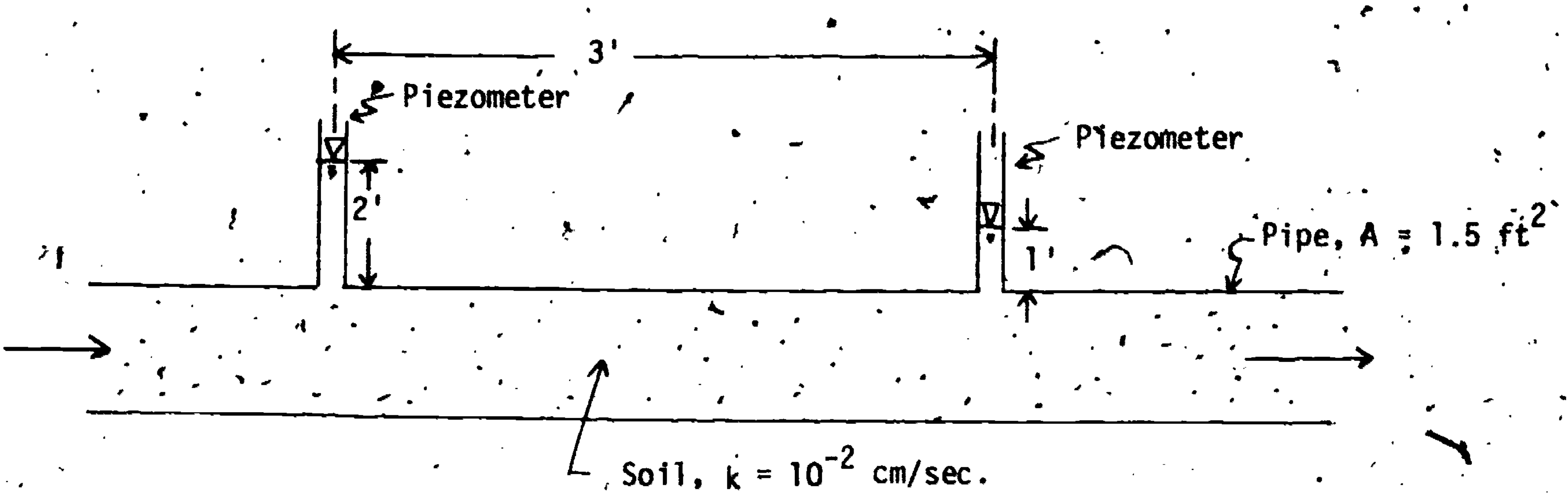
      c. Review the principle of continuity

      d. Review the principle of water "head"

      e. Limitations on Darcy's Law

      f. Example problem

i. Given:



Note: Neglect pipe friction losses

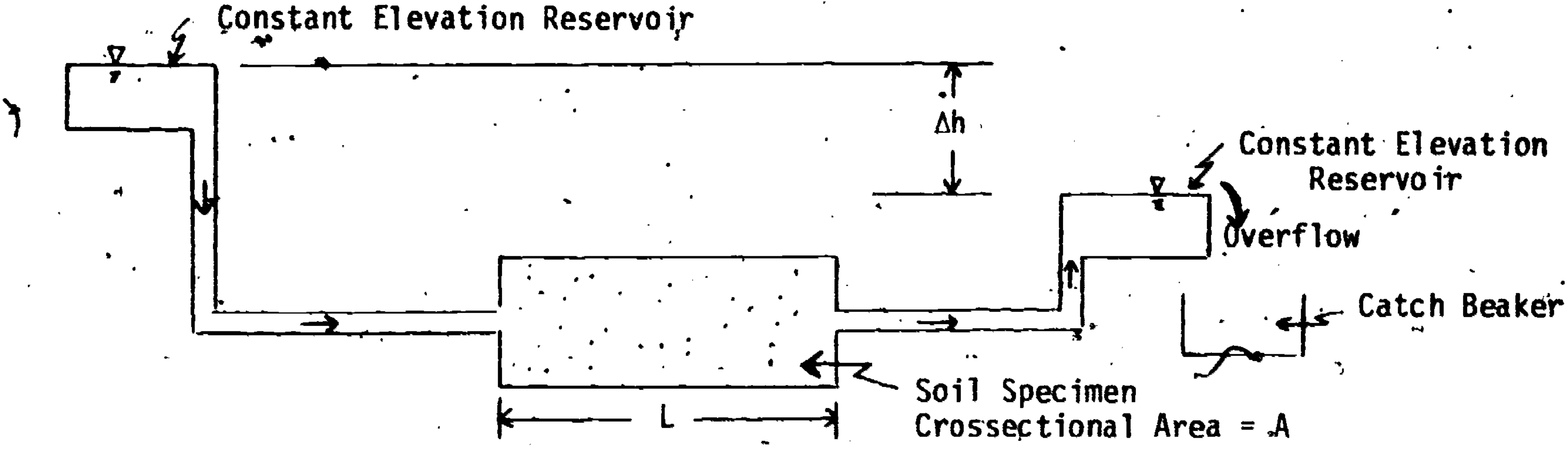
ii. Find:

a'. v
b'. Q
c'. Time required for water to flow between piezometers

4. Methods of determination

a. Laboratory constant head permeability test

i. A constant head loss is maintained across a soil specimen and the volumetric rate of flow of water through the specimen is determined.
ii. Experimental setup



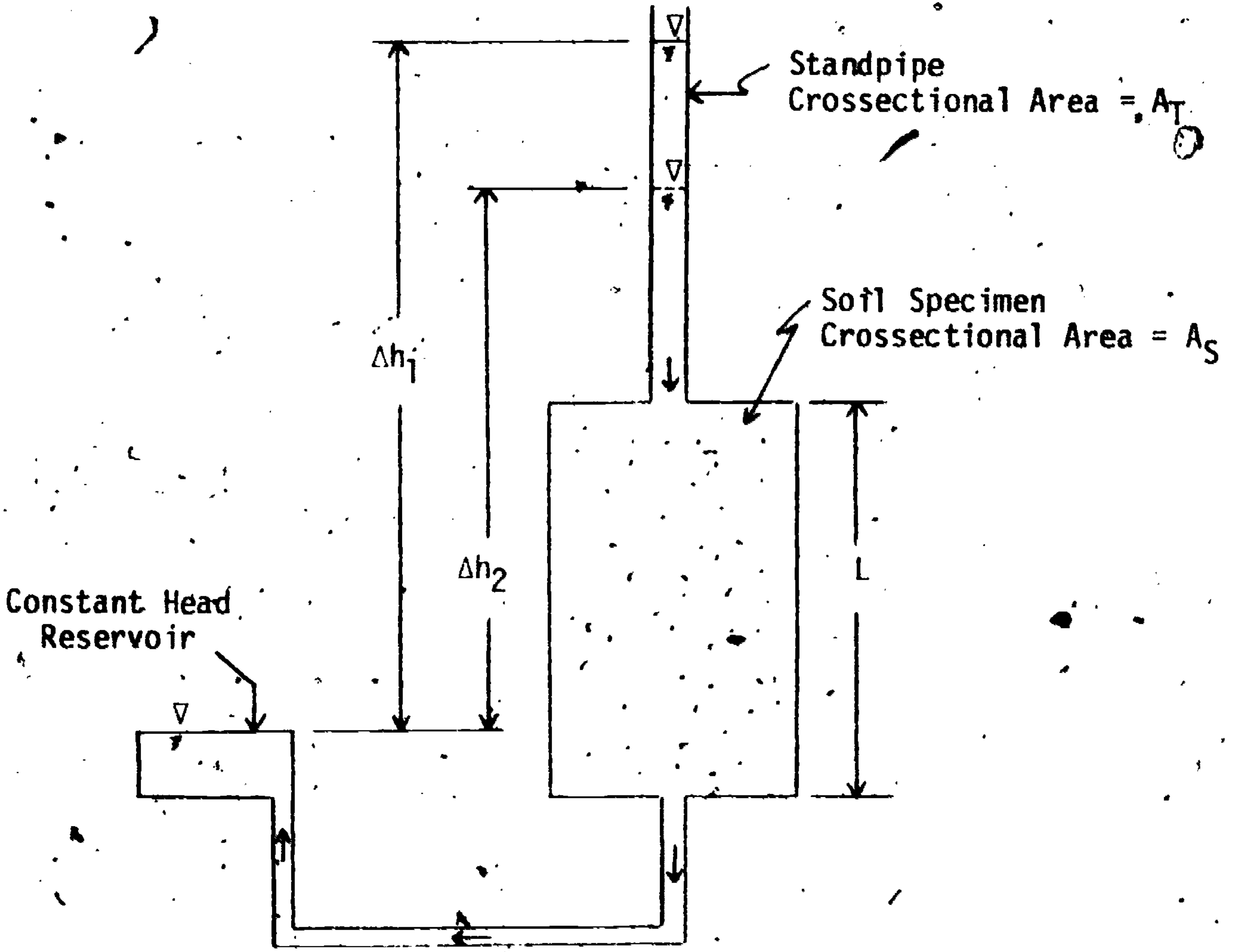
iii. Data reduction
a'. Q = kiA     k = Q/(Ai) = Q/( AΔh/L)
b'. Δh as shown
c'. L as shown
d'. A as shown
e'. Q = volume of water obtained in the catch beaker in some time, t, divided by that time

iv. Example Problem

a'. Given: $\Delta h = 3'$
$L = 6''$
$A = 0.25\ ft^2$
Weight of water recovered in beaker in 15 seconds = 100 gms.
b'. Find: $k$

b. Laboratory falling head permeability test

i. A variable head loss is maintained across a soil specimen and the head loss is measured as a function of time:
ii. Experimental setup



iii. Data reduction
a'. $k = \frac{L\, A_T}{A_S(t_2-t_1)} \ln[\Delta h_1/\Delta h_2]$
b'. L as shown
c'. $A_T$ as shown
d'. $A_S$ as shown
e'. $\Delta h_1$ as shown
f'. $\Delta h_2$ as shown
g'. $t_2$ time corresponding to $\Delta h_1$ reading
h'. $t_1$ time corresponding to $\Delta h_2$ reading

iv. Example problem

a'. Given: $A_T = 0.10\ ft^2$

$A_S = 0.50\ ft^2$

$L = 6"$

| t(sec) | Δh(ft) |
|---|---|
| 0 | 3 |
| 30 | 2.5 |

b'. Find: k

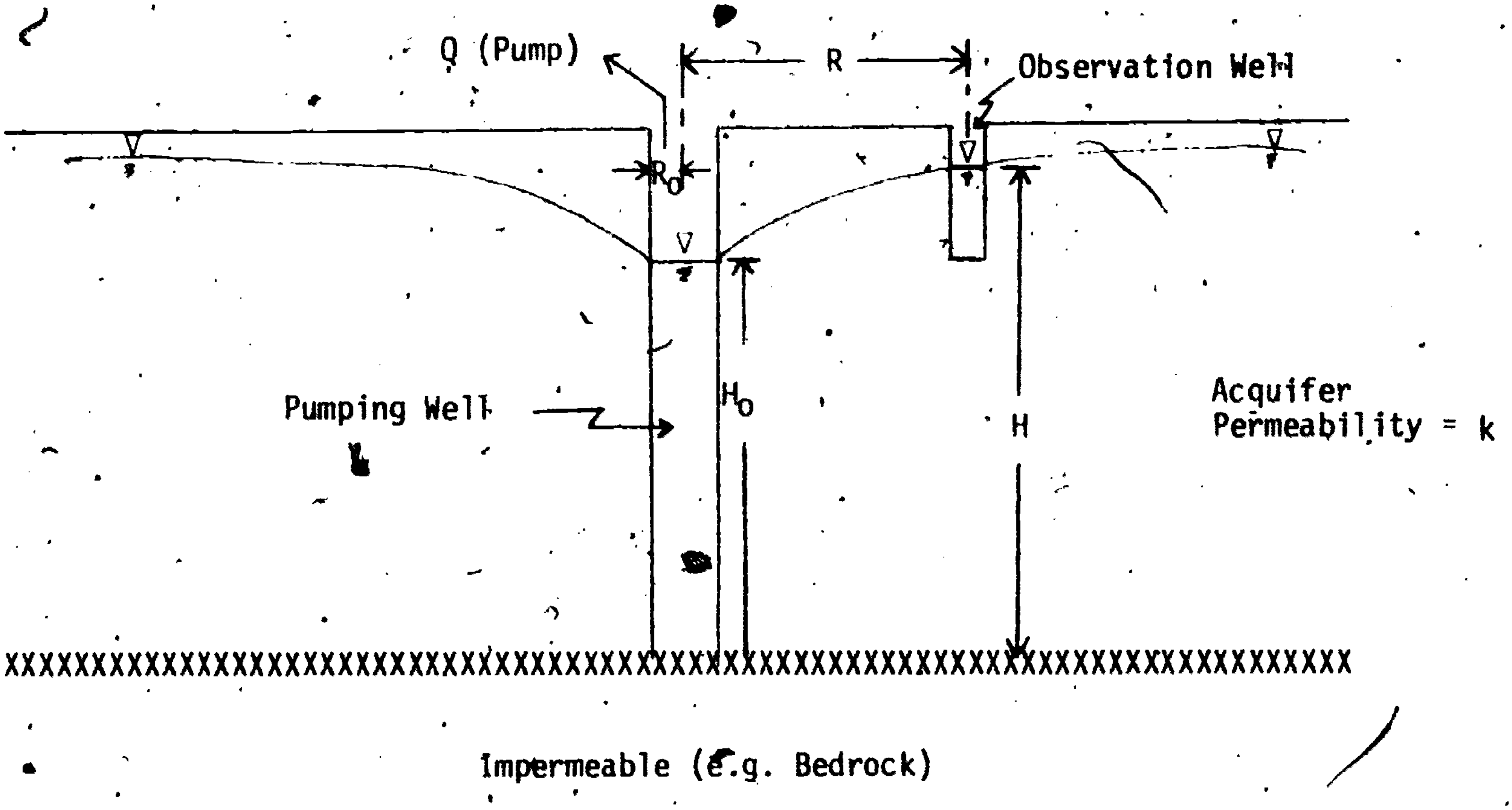
c. Laboratory consolidation test

d. Field soil permeability determinations are frequently made

- i. Advantages
- ii. Disadvantages

e. Field permeability test - Case 1

- i. Steady state flow to a fully penetrating well in a homogeneous acquifer
- ii. Geometry of problem:



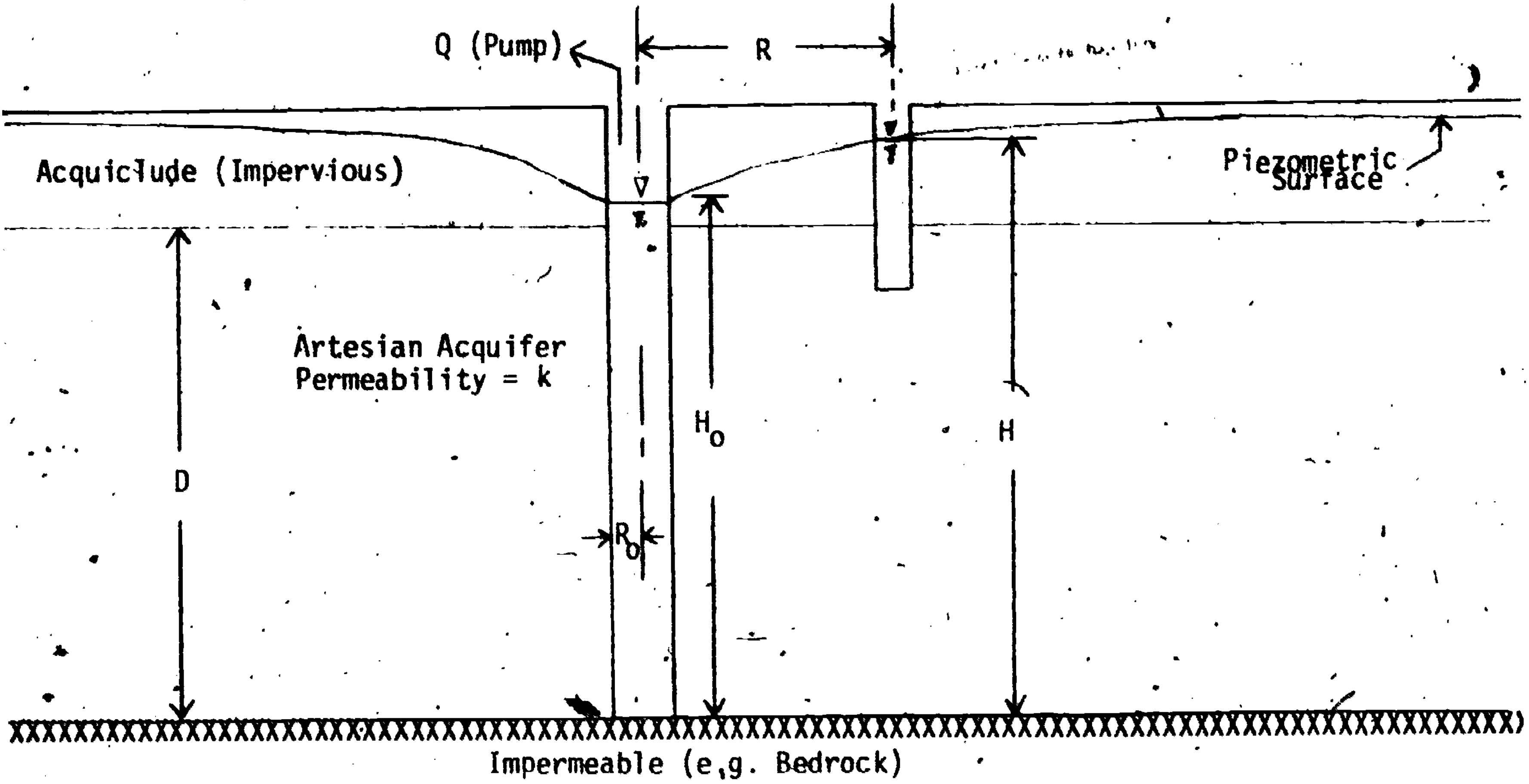
- iii. Three dimensional flow
- iv. Data reduction

a'. $$k = \frac{Q \ln (Ro/R)}{\pi\ (Ho^2 - H^2)}$$

f. Field permeability test - Case 2

- i. Steady state flow to a fully penetrating well in a homogeneous artesian acquifer.

ii. Geometry of problem:



iii. Three dimensional flow
iv. Data reduction

$$k = \frac{Q \ln (Ro/R)}{2\pi D (Ho-H)}$$

g. Other field permeability test solutions

h. Approximate relationship
    i. Hazen's formula for the permeability of clean sands
    ii. $k \approx C(D_{10})^2$

where: $k$ - Soil permeability (cm/sec.)
$D_{10}$ - Soil effective diameter (mm)
$C$ - Constant (Range = 1.0 to 1.5)

5. Primary factors affecting the permeability of one soil

    a. Density
    b. Degree of saturation
    c. Nature of the fluid flowing through the soil

6. Typical permeability values:

| Material | Permeability (cm/sec.) |
|---|---|
| Gravel | >1 |
| Coarse sand | $1-10^{-1}$ |
| Medium sand | $10^{-1}-10^{-2}$ |
| Fine sand | $10^{-3}-10^{-4}$ |
| Silt | $10^{-4}-10^{-5}$ |
| Clay | $10^{-6}$ or less |
| Rock | $10^{-12}$ or less |

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

ourse: ETC 411
eek No: 5

Outline of Weekly Lecture Notes

Prepared By: J.B.Thompson
Date: 11/5/73

ecture Subjects: Soil Compaction, Geostatic Stress in Soil

ssignment: Read - pp. 199-205, 505-517

Problems - 7-1, 7-2, 7-7, 13-2, 13-3

esentation

. Principle Soil Properties and Characteristics and Their Determination (continued)

A. Compaction characteristics

1. Definition

a. Compaction of a soil is the densification of the soil due to the expulsion of air from the soil voids

b. Different soils exhibit different compaction characteristics in that they exhibit varying responses to a compaction effort.

2. Utilization

a. Design of and control of the construction of engineered fills (engineered fills will be discussed in detail later)
i. Determine the soil water content range at which field compaction should be performed
ii. Determine the soil density range the contractor should achieve in fill placement
iii. Provide other soil properties and characteristics of the fill as it will be placed in the field

3. Example fills

a. Earth and rock fill dams

b. Backfills behind retaining structures

c. Highway and airfield subgrades

d. Grade fills for structural foundations

4. Purposes of soil compaction

a. Increase the strength of the soil

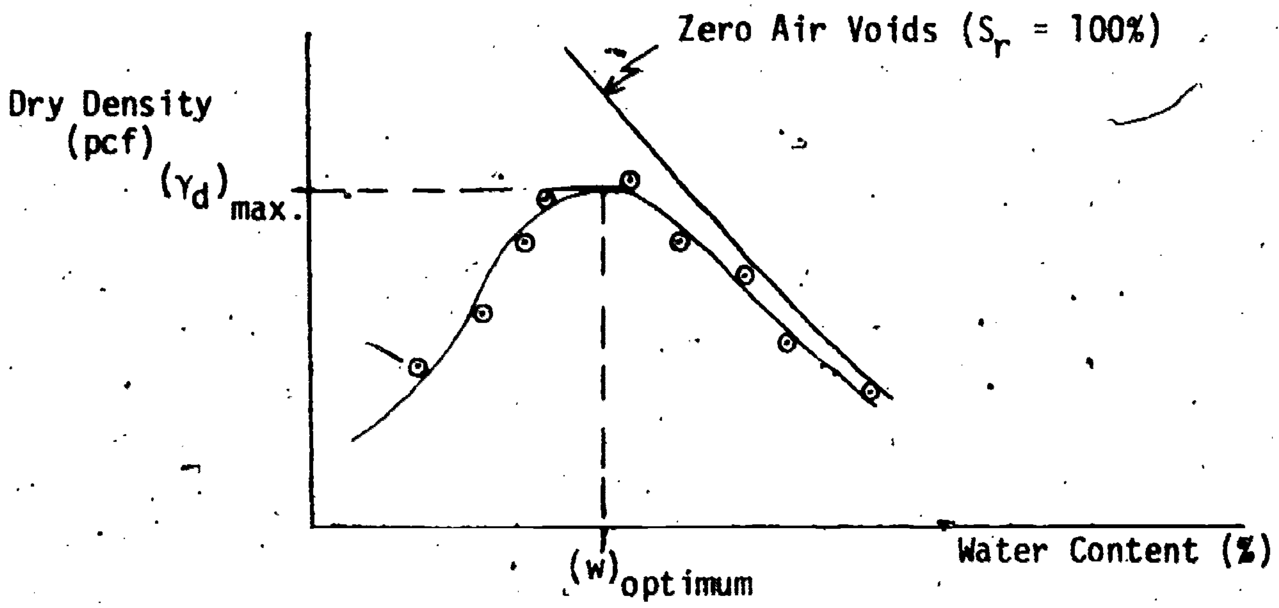
b. Decrease the compressibility of the soil

c. Decrease the permeability of the soil

5. Determination of the compaction characteristics of a soil

   a. Standard Proctor Compaction Test

      i. Description of equipment
      ii. Description of test procedure
      iii. Data reduction



      iv. Explanation of curve

   b. Modified Proctor Compaction Test

   c. Standard AASHO Compaction Test

   d. Modified AASHO Compaction Test

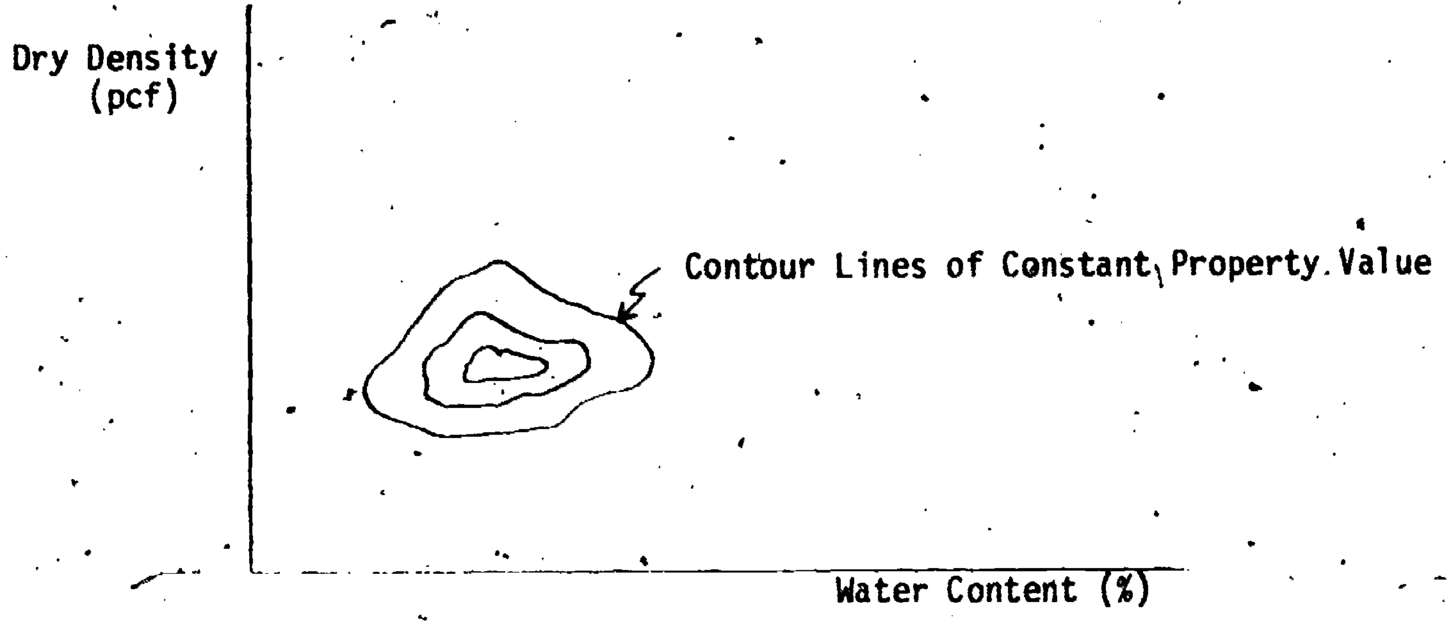
   e. Harvard Miniature Compaction Test

   f. Other kneading compaction tests

6. Determination of the other properties and characteristics of the compacted soil

   a. Test the compacted soil in the lab
      i. Permeability test
      ii. Stress-strain and strength tests

   b. Interpretation of the data
      i. Plot contours



ii. Select desired water content and dry density which must be achieved in the field

7. Fill specifications

   a. Specifications on field fill placement based on laboratory results

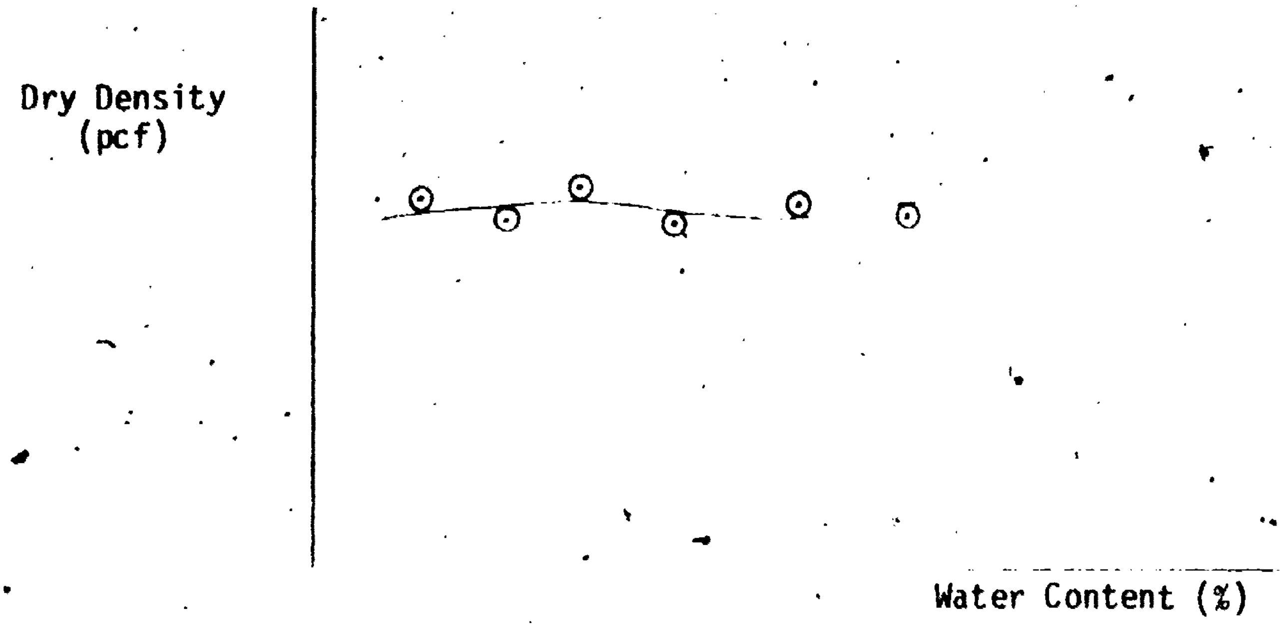
   b. Usually specify that contractor achieve X% of the Y test maximum dry density [e.g. 95% of modified AASHO maximum dry density] .

   c. Occasionally also specify the range in the water content at which the fill must be compacted in the field

8. Compaction characteristics of course grained soils

   a. Compaction test not usually conducted because it is not informative

   b. Typical compaction curve for coarse grained soil



   c. Dry density achieved insensitive to the water content of the soil

   d. Conduct relative density test

i. Description of equipment - standard ASTM equipment
ii. Description of test procedure - standard ASTM procedure
iii. Data reduction

e. Specify field density as some minimum relative density (e.g. 80%)

f. Note the difference between relative density and some percent of maximum dry density

B. Consolidation characteristics

1. Caused by a change in effective stress within the soil

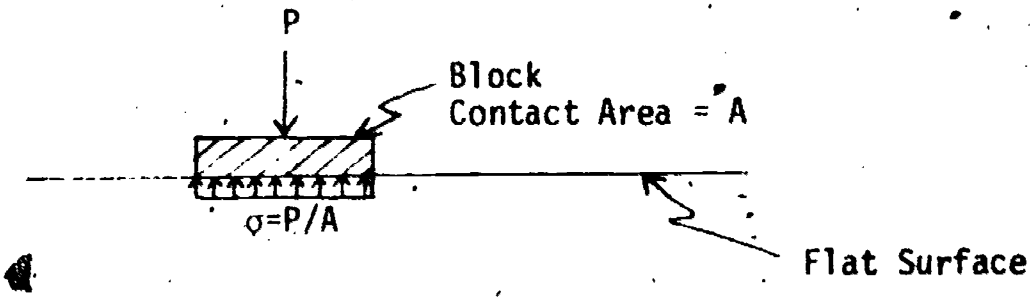
2. Must examine stress in soil before considering the subject of consolidation

3. Stress - general

   a. Stress is equal to the ratio of a force to the area over which it acts

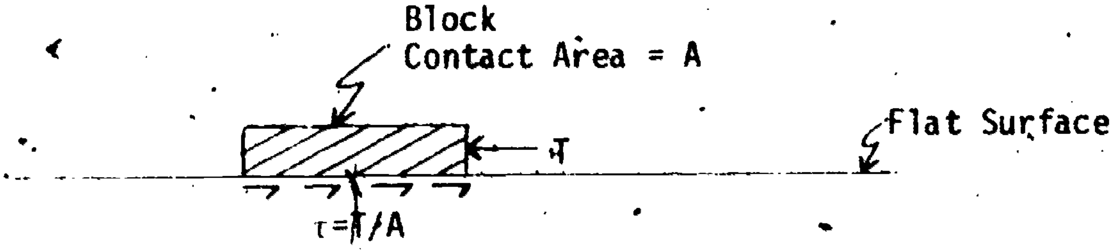
   b. Two types of stresses: normal stresses and shear stresses

   c. Normal stress ($\sigma$)
      i. Normal stress acts perpendicular to the plane on which it acts
      ii.



      iii. Units: (psf, tsf, Kg/cm$^2$)

   d. Shear Stress ($\tau$)
      i. Shear stress acts parallel to the plane on which it acts
      ii.



      iii. Units: (psf, ~~tsf,~~ Kg/cm$^2$)

4. Soils are more complicated because must be concerned with the stresses acting in all three phases

5. For the present will deal with the vertical normal stresses acting in a soil deposit

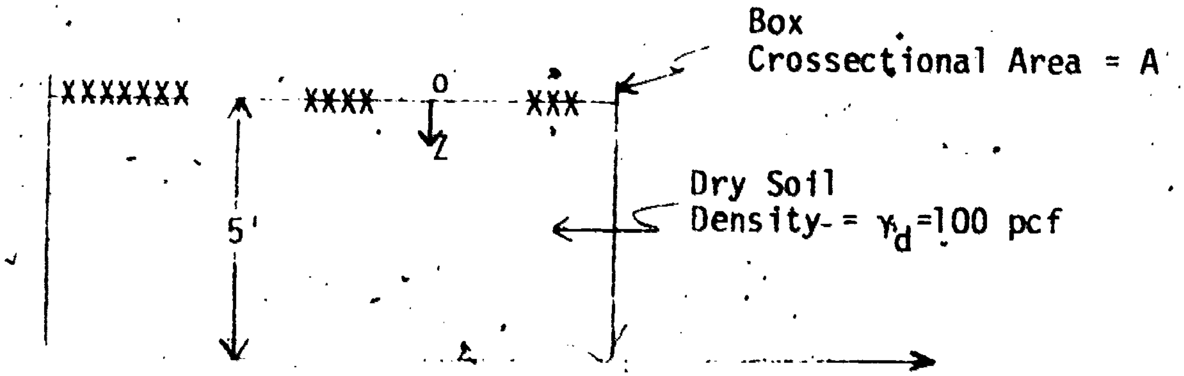
   a. Generally controls the amount of consolidation which will occur

6. Vertical "Total" normal stress ($\sigma_v$) acting in natural soil deposits

   a. Vertical normal stress acts in the vertical direction and on horizontal planes

   b. Total stress: Total force acting on some plane in the soil deposit divided by the crossectional area of that plane

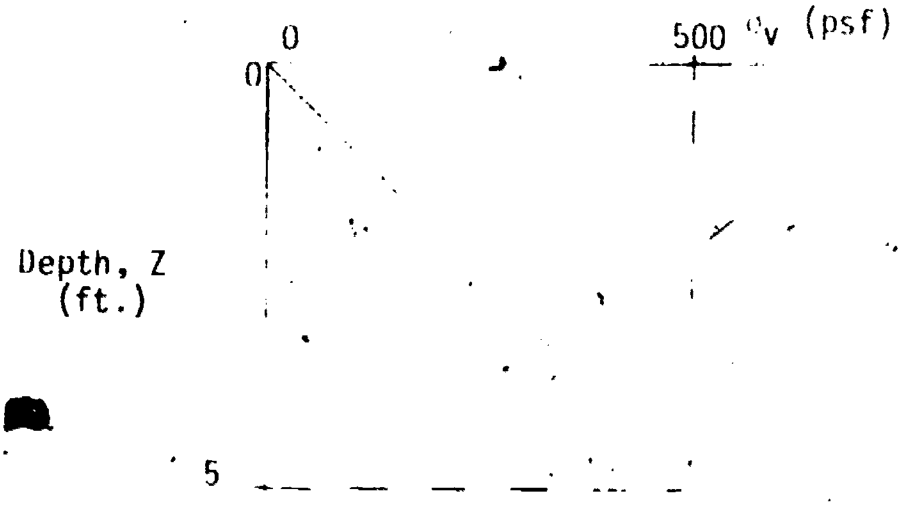
   c. Example problem
   i. Dry soil in a box



ii. Variation in vertical "Total" normal stress ($\sigma_v$) with depth in the box:

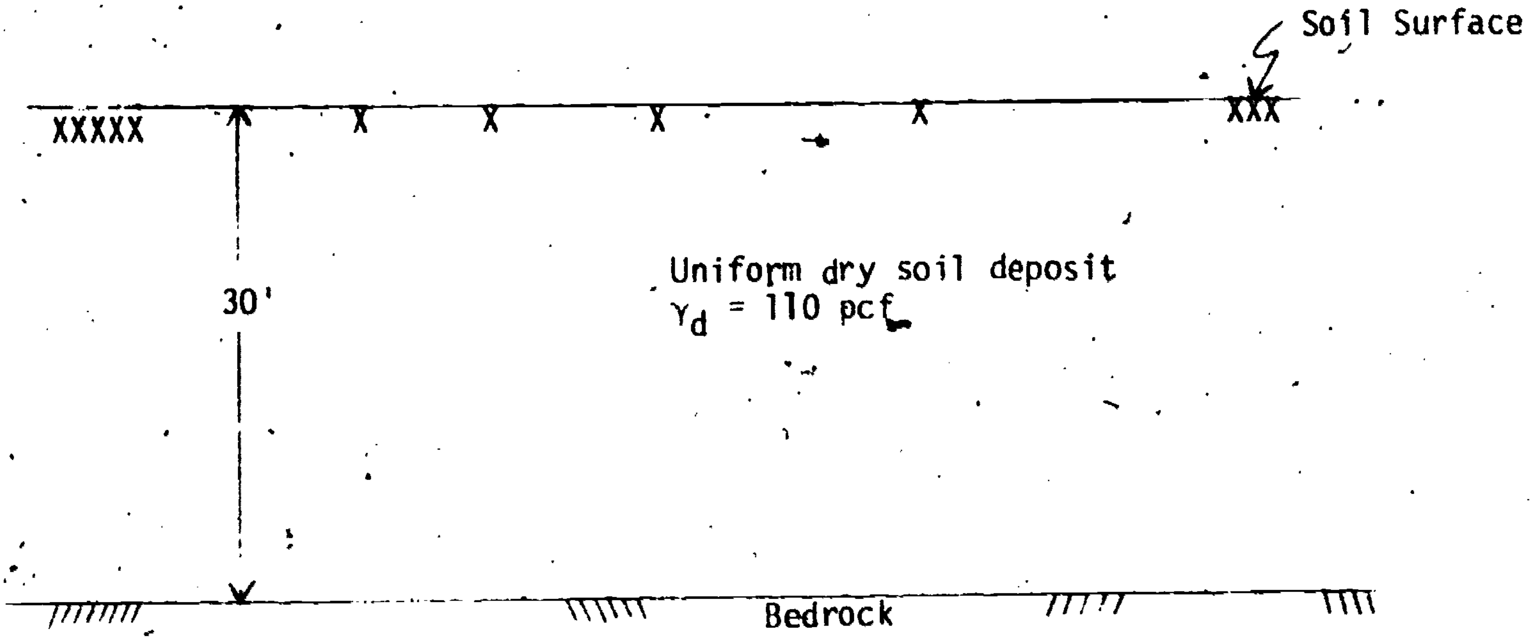
a'. At some depth Z: Total vertical force on horizontal plane = $\gamma_d AZ = 100AZ$
Crossectional area over which it acts = A
Vertical "Total" normal stress = $\sigma_v = \frac{\gamma_d AZ}{A} = 100Z$

b'. Answer:



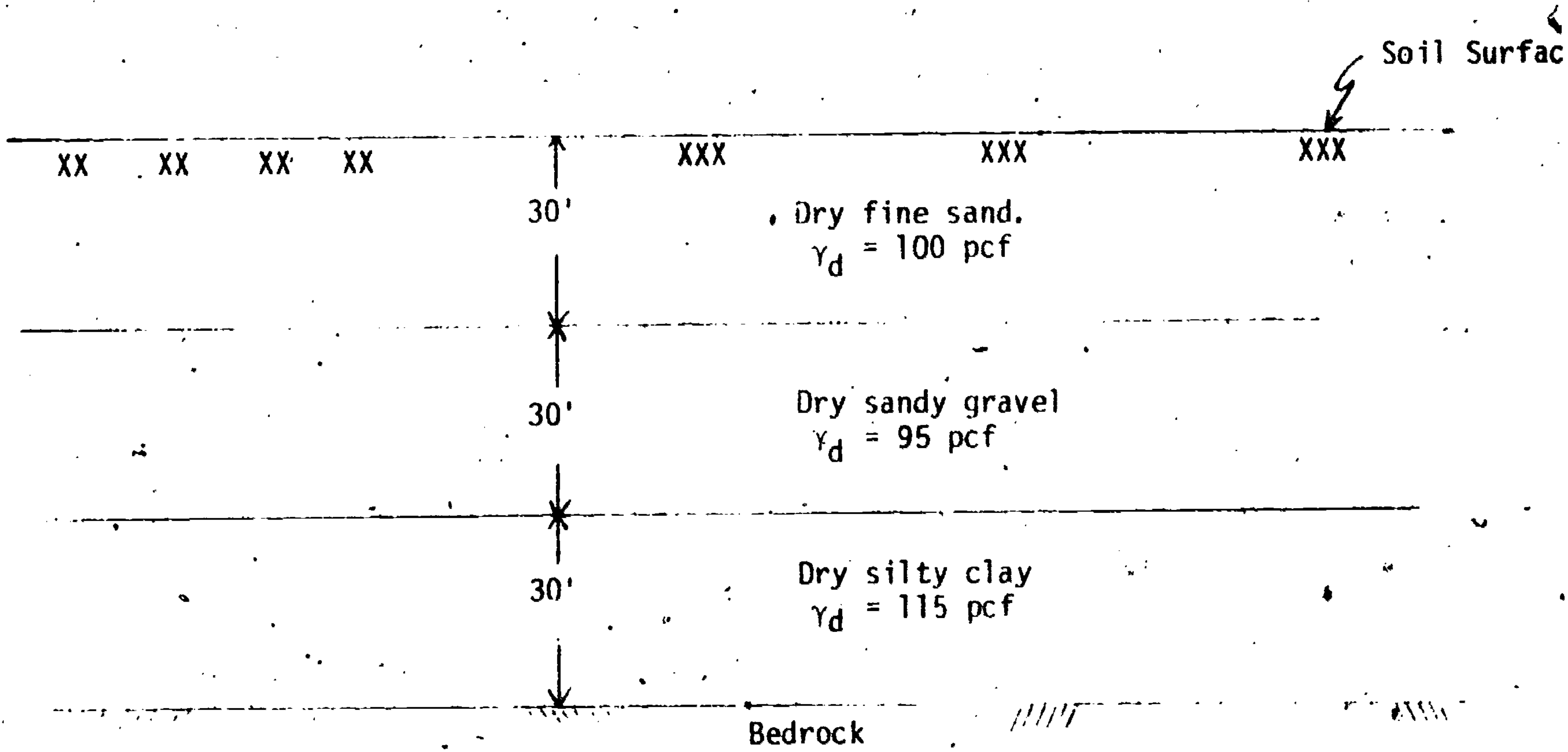
iii. Effect on the above plot if the crossectional area of the box were changed
   - a'. None - area cancels out
   - b'. Vertical "Total" normal stress is independent of the crossectional area considered

d. Example problem (Uniform dry soil deposit)
   i. Given:



   ii. Plot: Variation in vertical "Total" normal stress with depth

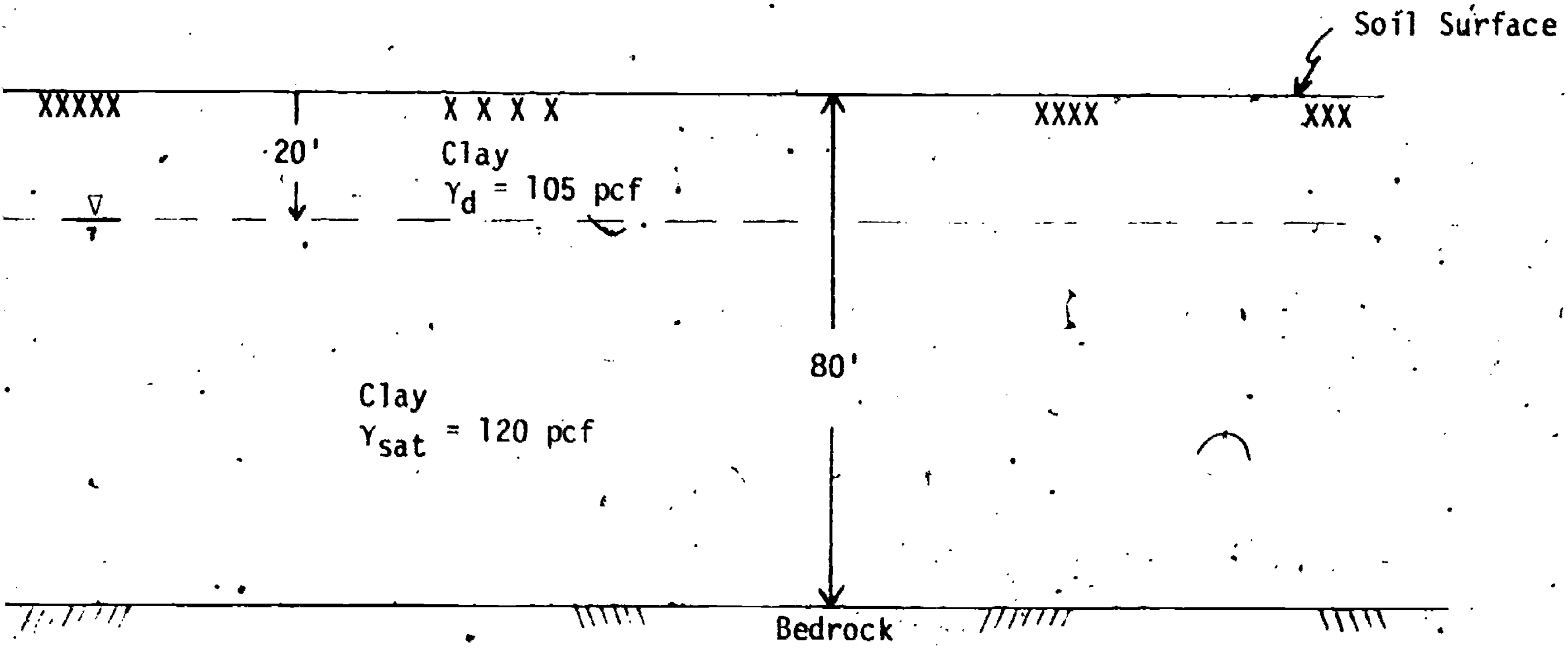
e. Example problem (Layered dry soil deposit)
   i. Given:



ii. Plot: Variation in vertical "Total" normal stress with depth

f. Example problem (Water present)

i. Given:



ii. Plot: Variation in vertical "Total" normal stress with depth

iii. Note: Soil above the ground water table may be saturated or partially saturated due to capillary action, rainfall, etc.

I. Hour Exam

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411 Prepared By: J.B.Thompson

Outline of Weekly Lecture Notes

Week No: 6 Date: 11/5/73

Lecture Subjects: Soil Consolidation and Stress-Strain and Strength Characteristics

Assignment: Read - pp. 106-158

Problems - To be assigned

## Presentation

I. Principle soil properties and characteristics and their determination (continued)

A. Consolidation characteristics (continued)

1. Definition

a. Consolidation of a soil is the densification of the soil due to the expulsion of water from the soil voids caused by a change in the effective stress acting on the soil

b. Different soils exhibit different consolidation characteristics in that they will undergo different rates of densification and different amounts of ultimate densification in response to a given change in effective stress

2. Utilization

a. Computation of the ultimate amount of consolidation settlement and the rate of consolidation settlement a soil deposit will experience as the result of a change in the effective stress acting on the soil

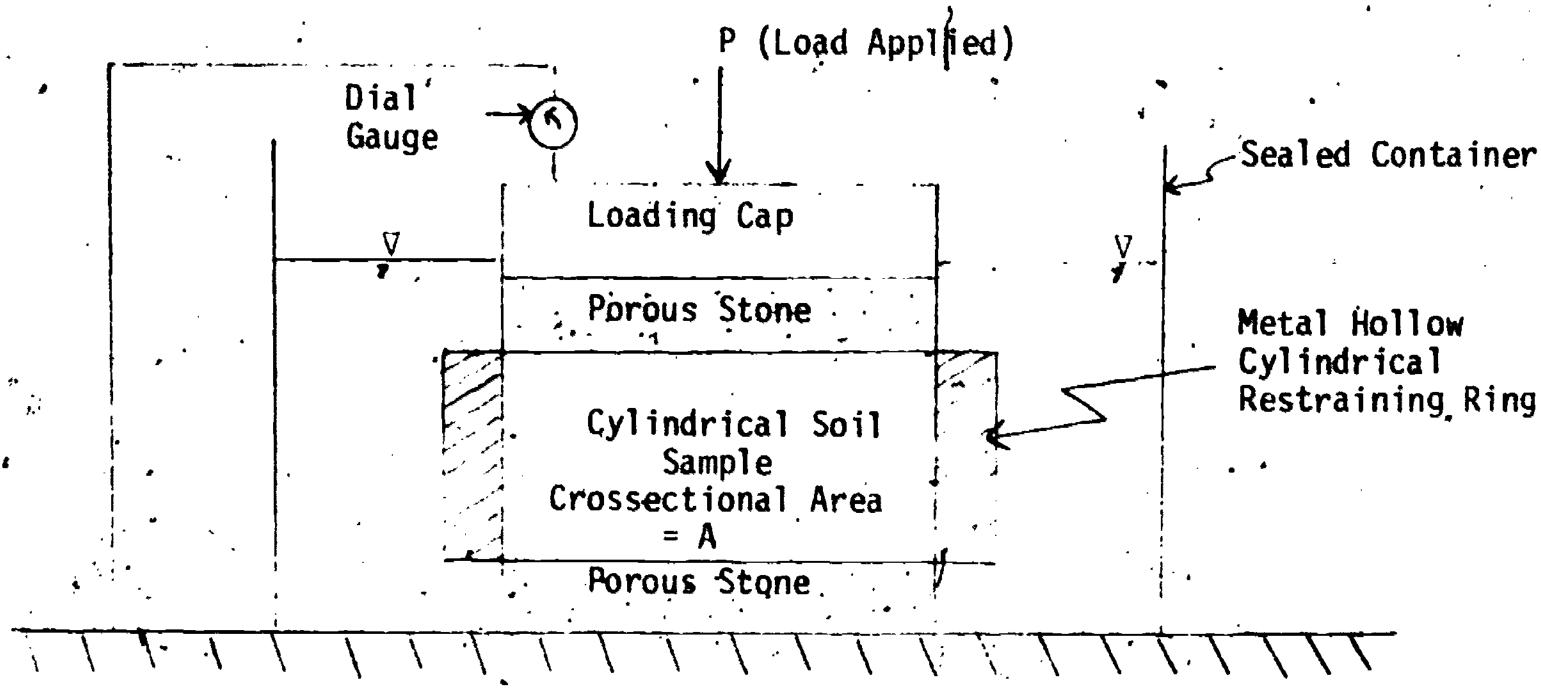
b. These computed values for settlement are utilized in the design of foundations such as:
   - i. Spread footings
   - ii. Wall footings
   - iii. Piles
   - iv. Caissons

3. Determination of the consolidation characteristics of a soil

a. General description
   - i. Test an undisturbed cylindrical sample of the soil obtained from the field
   - ii. Simulate field displacement conditions by prohibiting lateral displacements of the soil sample during testing
   - iii. Provide for free drainage of the soil sample during testing in order to meet theoretical boundary conditions utilized in data analysis
   - iv. Apply load increments to the soil sample during the test and allow the soil to completely consolidate under each load before changing the load

b. Experimental setup

i. Sketch



ii. Load applied through a loading frame

iii. Dial gauge measures the compression of the soil sample

c. Test procedure

i. Prepare the sample and make the initial sample measurements

ii. Set up the equipment

iii. Apply the first pressure (1/4 Kg/cm$^2$) and measure the sample compression with time until all compression has occured (or for about 24 hours)

iv. Apply the second pressure (1/2 Kg/cm$^2$) and measure the sample compression with time until all compression has occurred (or for about 24 hours)

v. Apply the successive pressures and measure the sample compression with time until all compression has occurred (or for about 24 hours)
  - Each successive pressure is twice the prior pressure applied
  - Maximum pressure applied in test exceeds the maximum pressure to be applied in the field

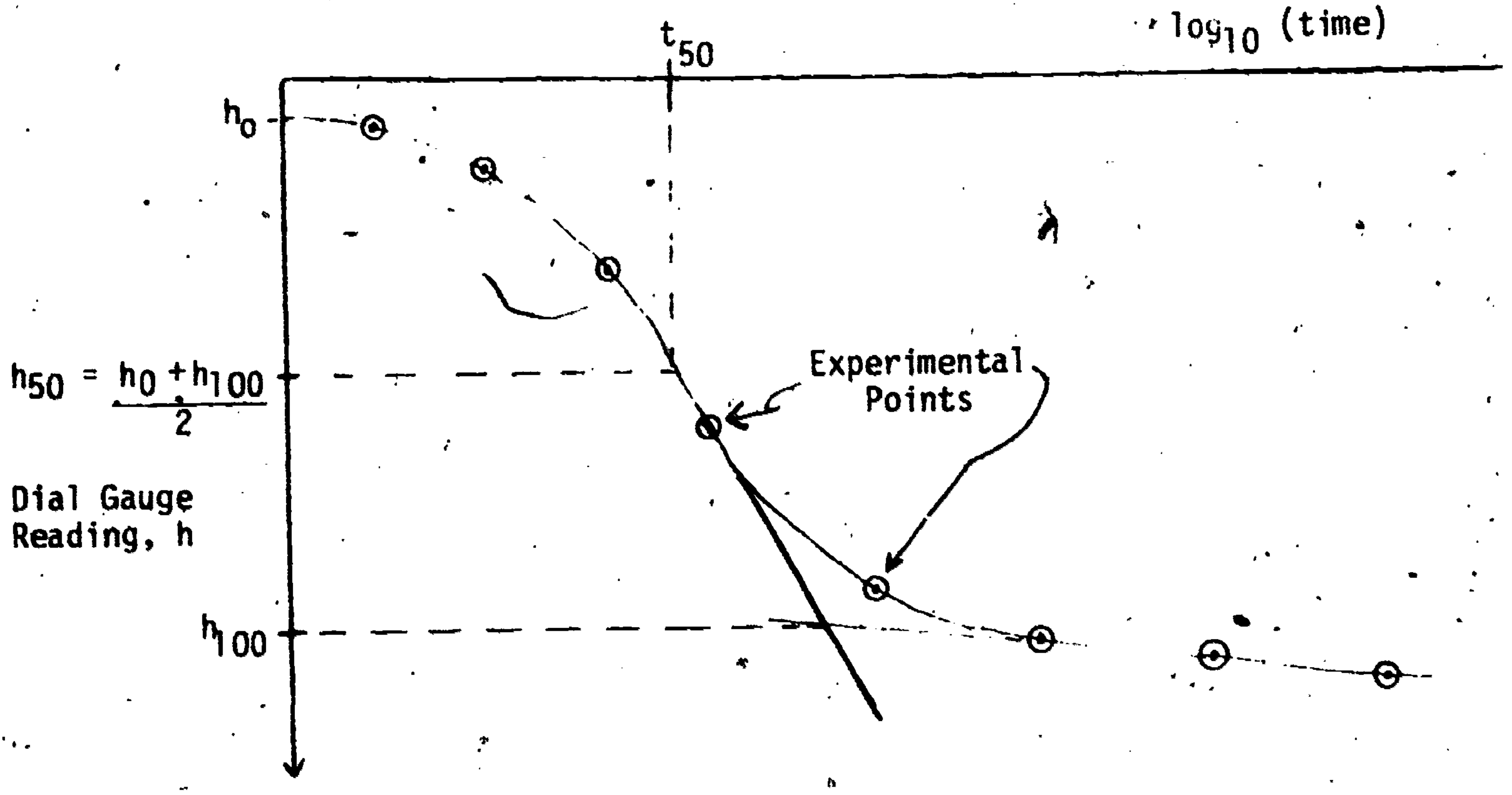
vi. Reduce the pressure on the sample in steps and record the ultimate swell of the sample resulting.

vii. After the sample is completely unloaded, preform a water content test on the entire sample immediately

d. Data reduction

i. Sample compression versus time for each load increment and $c_v$ computation

- Plot and necessary constructions



-$c_v$ computation (coefficient of compressibility)

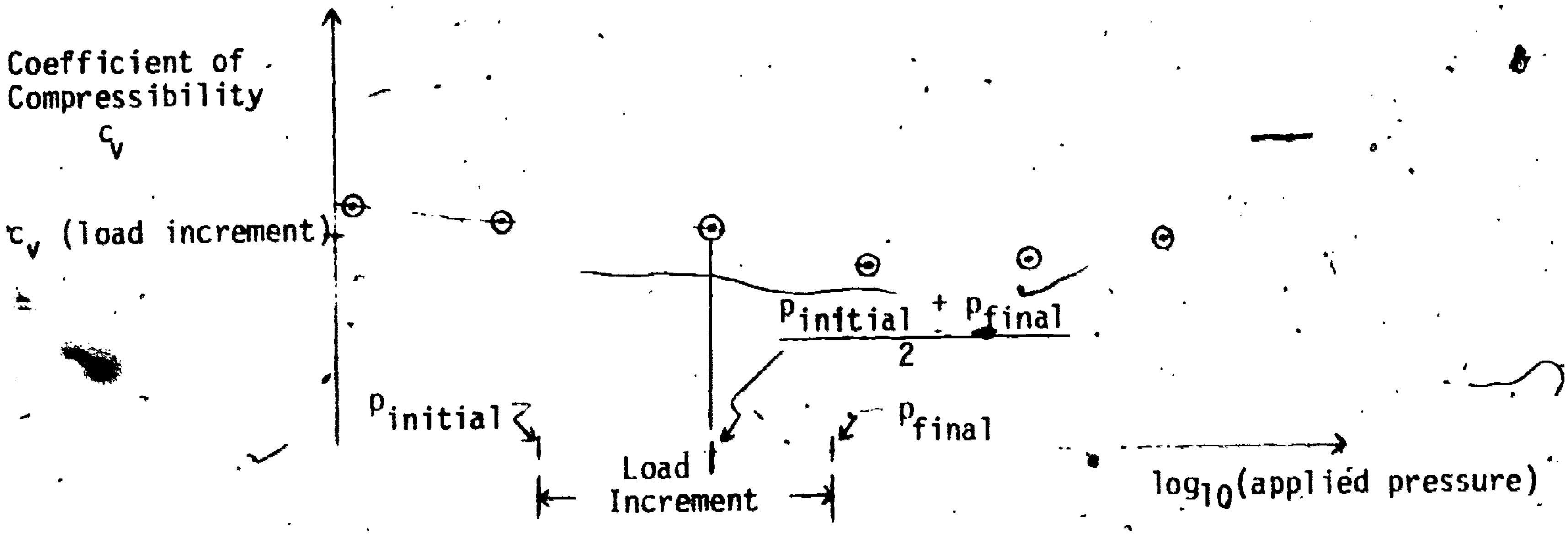
$$c_v = \frac{0.197}{t_{50}} (H/N)^2 \quad (cm^2/sec.)$$

where: $t_{50}$ = time at 50% consolidation compression [see plot above] (sec.)
$H$ = sample thickness (cm.)
$N$ = number of free drainage boundaries (1 or 2 )

Note: A value for $c_v$ is computed for each load increment applied to the sample

Note: $c_v$ is utilized in the calculation of the rate at which settlement will occur

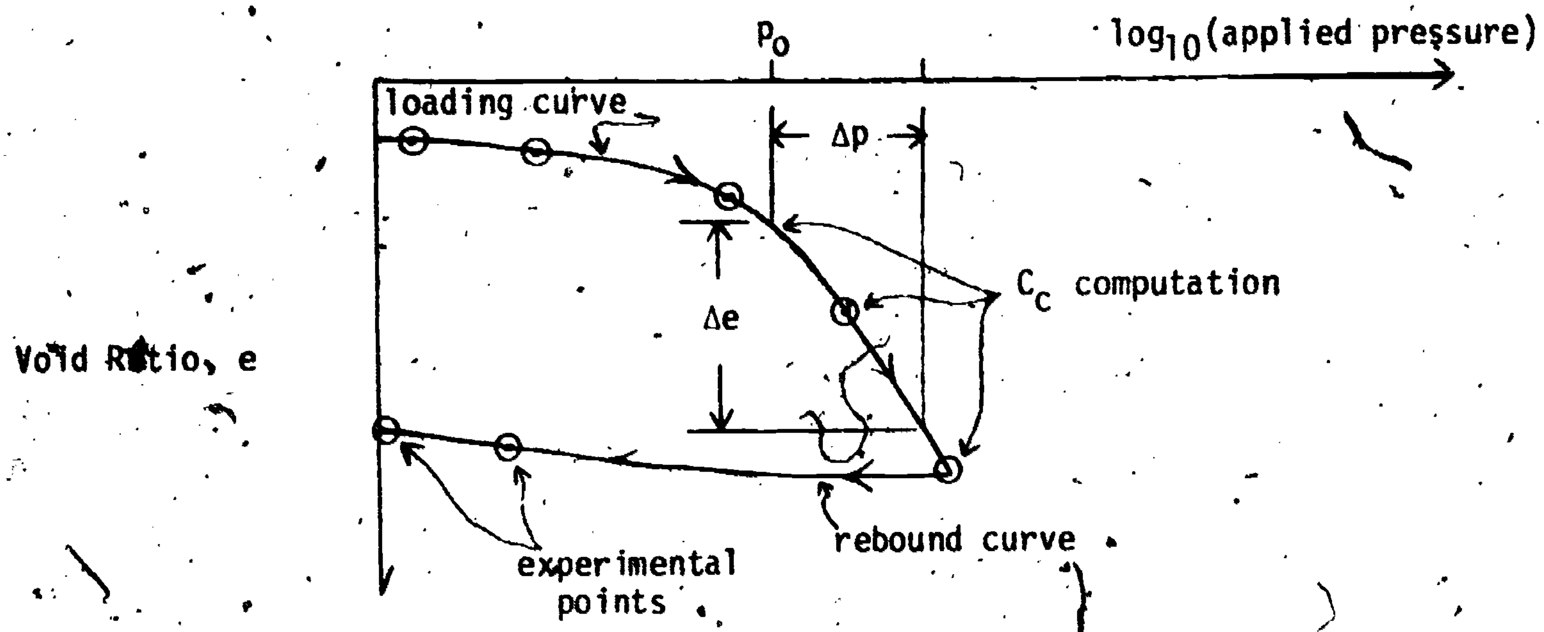
ii. Summary plot of $c_v$ values computed for each load increment applied to the sample



- $c_v$ computed for each load increment is plotted at the average pressure which existed on the soil sample during the application of the load increment

- $c_v$ is pressure dependent
- Note that applied pressures are vertical normal effective stresses

iii. Summary plot of the ultimate sample compression resulting from each applied pressure
- Plot the final void ratio, e, reached under each applied pressure versus the base ten logarithm of that pressure
- Plot



Note: Applied pressures are vertical normal effective stresses

- Relating void ratio to the measured dial gauge readings

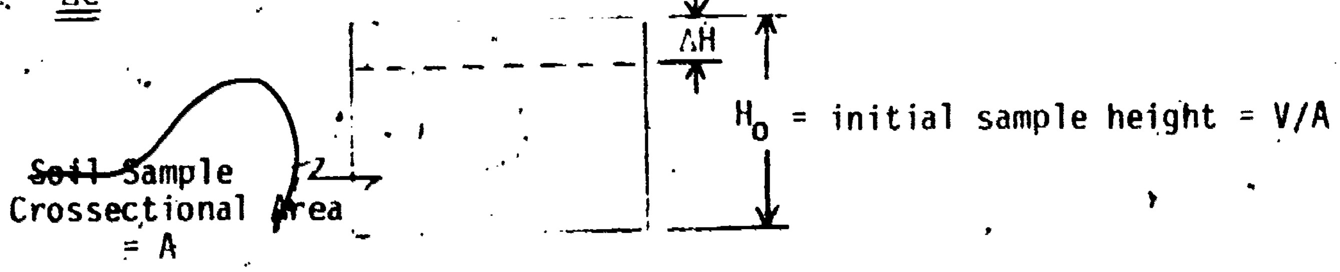
$e_0$ = initial void ratio @ zero applied pressure

$$e_0 = \frac{V_v}{V_s} = \frac{V - V_s}{V_s} = \frac{V}{V_s} - 1 = \frac{VG_s\gamma_w}{W_s} - 1$$

where: $V$ = initial sample volume ($A \times H_0$)
$G_s$ = specific gravity of the solids
$\gamma_w$ = unit weight of water
$W_s$ = weight of solids in sample (determined at test end)

$e = e_0 - \Delta e$ = soil void ratio

$\underline{\underline{\Delta e}}$



$\Delta H$ = measured dial gauge change

$$e_o = \frac{(V_v)\ \text{initial}}{V_s} = \frac{V\ \text{initial} - V_s}{V_s} = \frac{H_o A - 1}{V_s}$$

$$e_{final} = \frac{(V_v)_{final}}{V_s} = \frac{(H_o - \Delta H)\ A}{V_s} - 1$$

$$\Delta e = e_o - e_{final} = \left[\frac{H_o\ A}{V_s} - 1\right] - \left[\frac{(H_o - \Delta H)A}{V_s} - 1\right] = \frac{\Delta H\ A}{V_s}$$

$$\Delta e = \frac{\Delta HA}{V_s} = \frac{\Delta H\ V/H_o}{V_s} = \frac{\Delta H[(V_v)_{initial} + V_s]}{H_o\ V_s} = \frac{\Delta H}{H_o}(1 + e_o)$$

$$e = e_o - \frac{\Delta H}{H_o}(1 + e_o)$$

where: $e_o$ = initial void ratio
$\Delta H$ = measured dial gauge change
$H_o$ = initial soil sample height

- Compression Index

  Slope of the void ratio versus $\log_{10}$ (applied pressure) plot in the portion shown

  $$C_c = \text{Compression Index} = \frac{-\Delta e}{\log_{10}\left(\frac{P_o + \Delta P}{P_o}\right)}$$

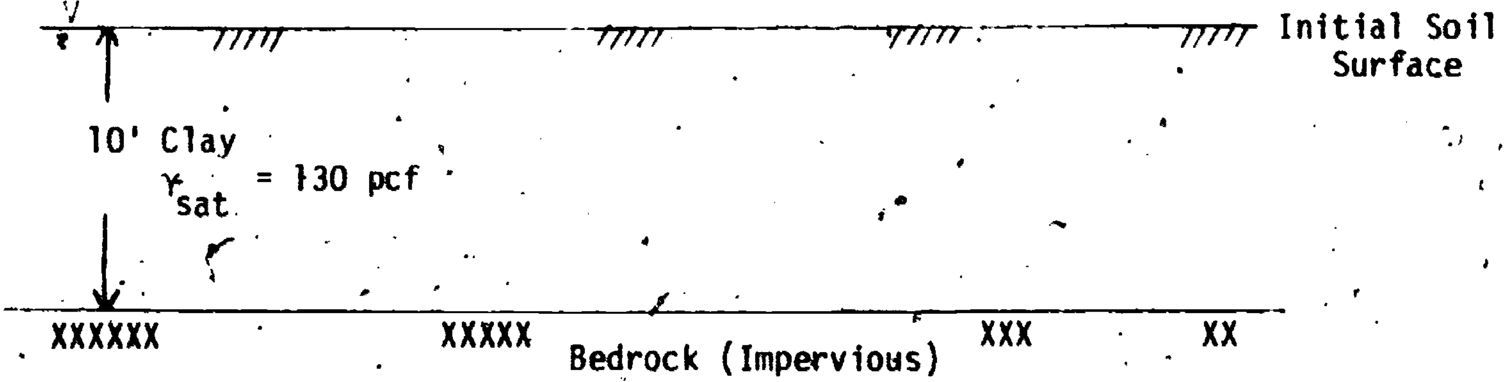
  Where: $\Delta e$ = change in void ratio corresponding to the change in applied pressure
  $p_o$ = some initial applied pressure
  $\Delta P$ = a change in the applied pressure

  Utilized in computations of ultimate settlement

- This summary plot of the ultimate sample compression from each applied pressure is utilized in computing the ultimate settlement which will occur in the field due to some change in applied pressure

4. Example problem (illustrate application)

   a. Given:
      i. Initial soil profile

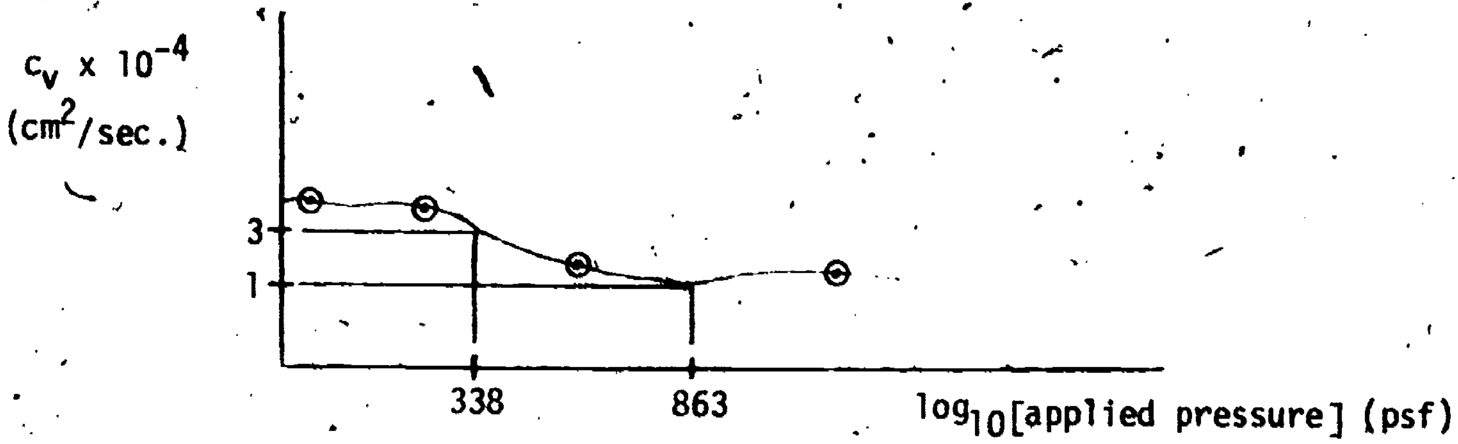


ii. Final soil profile: Same as above with 5 feet of fill @ $\gamma$ = 105 pcf placed atop the initial soil surface

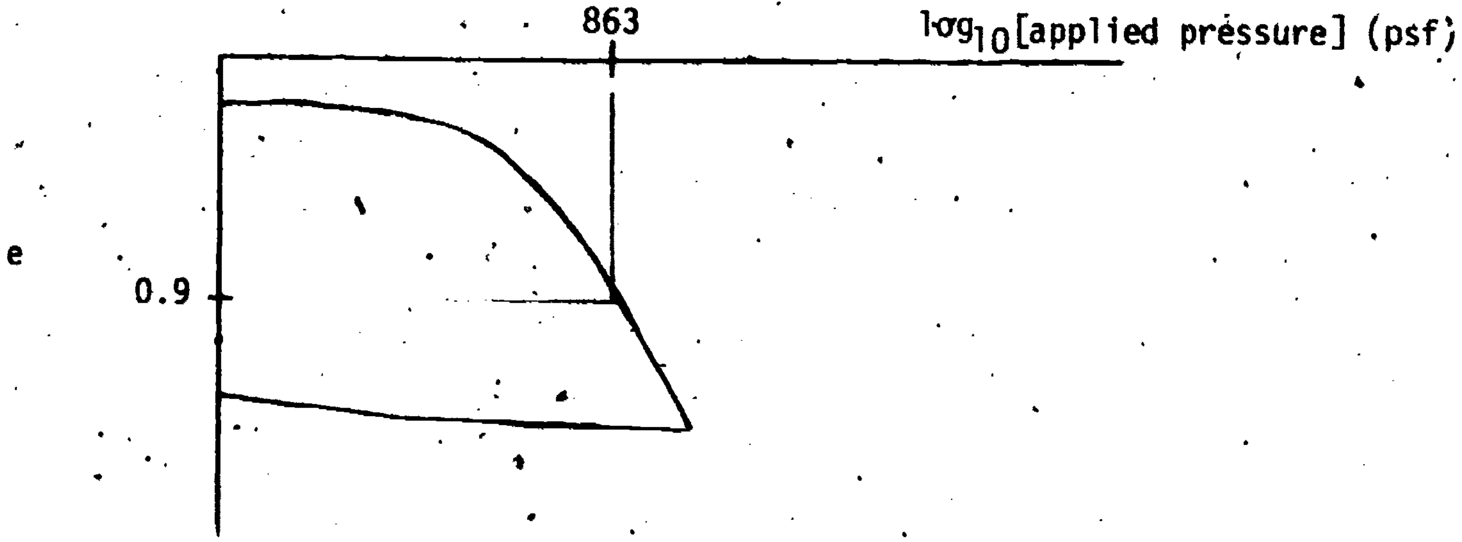
iii. Consolidation test results

- Performed on sample taken from a depth of 5 feet below the initial soil surface ($e_0$ = 1.0)

- $c_v$ vs. $\log_{10}$ (applied pressure) plot



- e vs. $\log_{10}$ (applied pressure) plot



b. Find:

i. The ultimate settlement of the clay surface

ii. The settlement of the clay surface which will occur in one year after fill placement

B. Stress-strain and strength characteristics

1. Definition

a. Soil stress-strain characteristics are soil properties which describe the compression of the soil resulting from a change in the stress acting on it

b. Soil strength characteristics are soil properties which describe the maximum load the soil can support without collapsing

2. Utilization

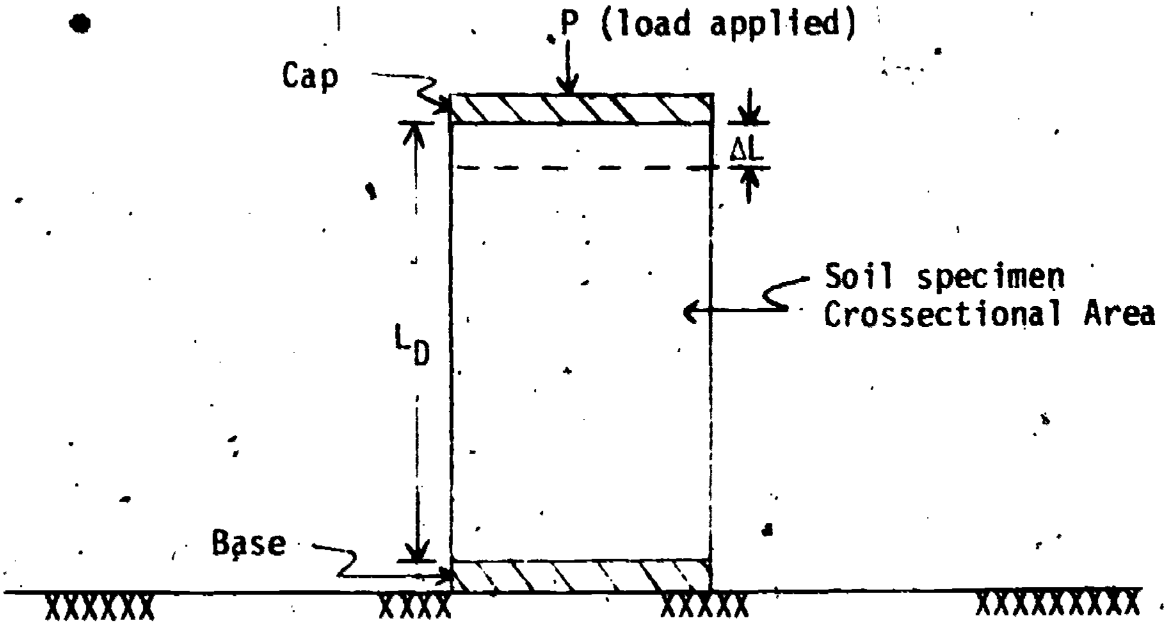
a. Soil stress-strain characteristics are utilized in the computation of the probable compression a certain soil mass will undergo as a result of a change in the stress acting on it

b. Soil strength characteristics are utilized in the design of various soil engineering problems in which collapse of the soil due to overloading is a limiting factor such as
   - i. Soil earth pressures against retaining structures
   - ii. Bearing capacity of foundations
   - iii. Stability of slopes

Note: Soil stress-strain characteristics are, in general, utilized only in advanced designing and will not be emphasized herein.

3. Simplified illustration of stress, strain, and strength

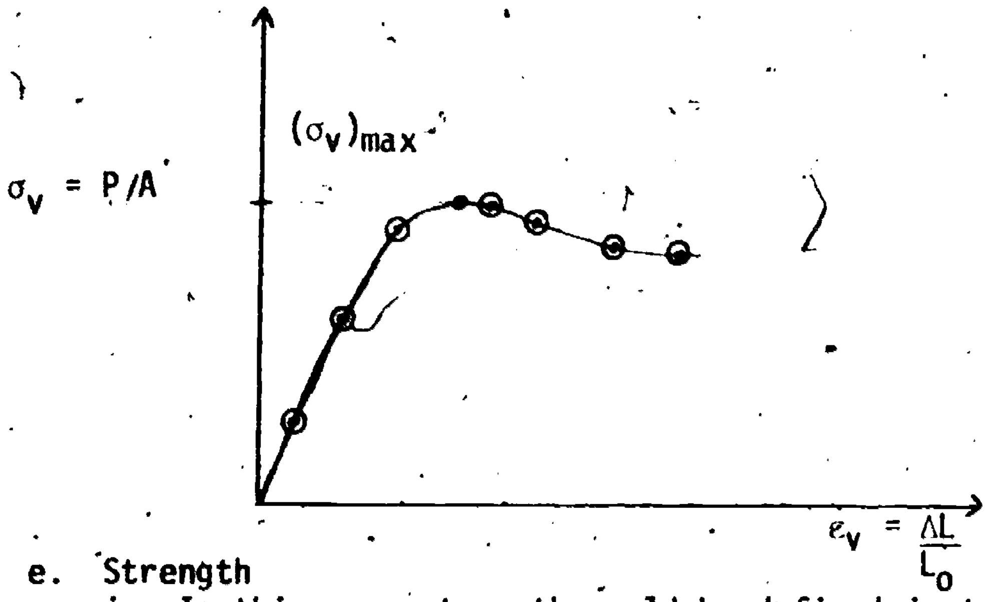
a. Rectangular soil sample to which a vertical load, P, is applied producing a change in length, ΔL:



b. Stresses
   - i. Vertical normal stress = $\sigma_v$ = P/A
   - ii. Horizontal normal stress = $\sigma_h$ = 0 (exposed to air; use gauge pressures)

c. Strain
   - i. Vertical strain = $\epsilon_v$ = $\Delta L/L_0$
   - ii. Horizontal strain = $\epsilon_h$ = 0 (as shown)

d. Stress-strain curve
   - i. As $\sigma_v$ is changed $\epsilon_v$ will change
   - ii. $\sigma_h$ and $\epsilon_h$ remain at 0
   - iii. Plot



e. Strength
   i. In this case strength could be defined in terms of the maximum load and vertical normal stress the soil specimen was able to withstand
   ii. $(\sigma_v)_{max}$ is shown above

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411
Week No: 7

Outline of Weekly Lecture Notes

Prepared by: J.B.Thompson
Date: 11/ 5/73

Lecture Subjects: Soil Stress-Strain and Strength Characteristics

Assignment: Read - pp. 163-196, 223-233

Problems - To be assigned.

Presentation

I. Principle soil properties and characteristics and their determination (continued)

  A. Stress-strain and strength characteristics (continued)

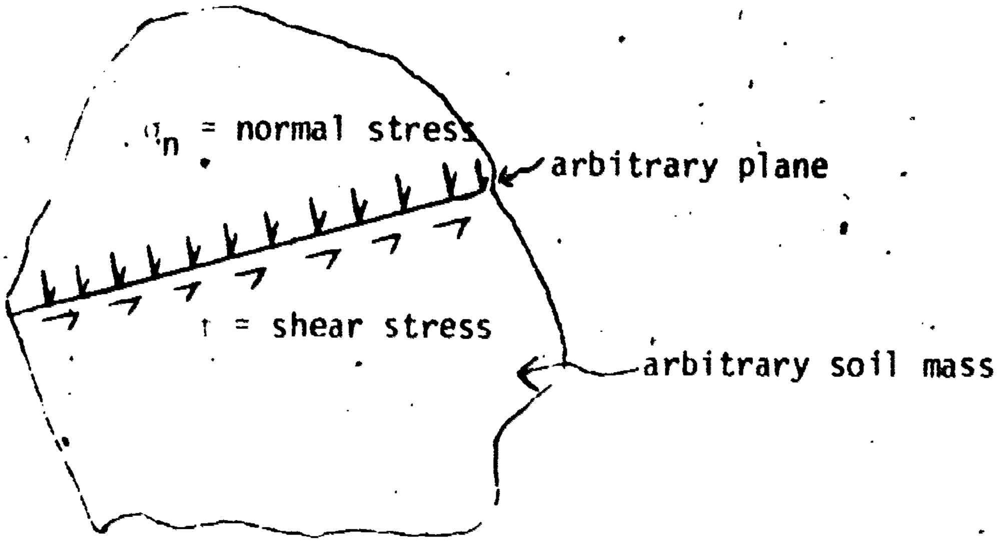
    1. Theory of soil strength

      a. Soil fails by shear when the shear stress along some plane in the soil exceeds the maximum shear stress the soil can withstand.

      b. Stresses acting on a plane

        i. Stress on a plane can be described completely by the shear stress and normal stress acting.

        ii. Diagram.



      c. Mohr-Coulomb Theory

        i. Establishes an equation for the failure shear stress along any arbitrary plane

        ii. Equation:

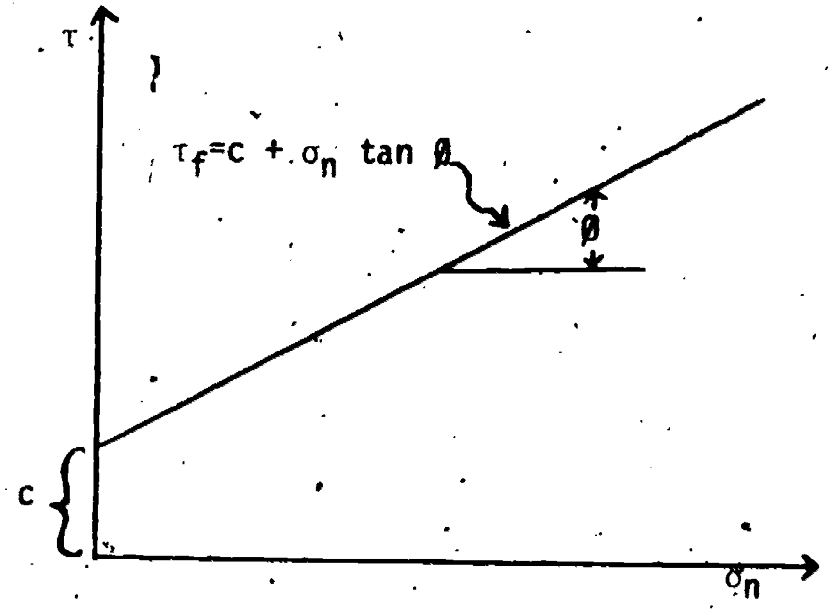
$$\tau_f = c + \sigma_n \tan(\phi)$$

where: $\tau_f$ = failure shear stress on the plane
$\sigma_n$ = normal stress acting on the plane
c = soil cohesion
$\phi$ = soil angle of internal friction

iii. The two basic soil properties are the soil cohesion, c, and the soil angle of internal friction, $\phi$.

iv. Failure will not occur if the actual shear stress acting on the plane does not equal or exceed $\tau_f$.

v. Graphical representation of the Mohr-Coulomb Equation:



2. Soil strength properties which must be determined are the soil cohesion, c, and the soil angle of internal friction, $\phi$.

3. Determination of the strength characteristics of a soil

   a. Several test techniques are utilized and each is advantageous under certain conditions.

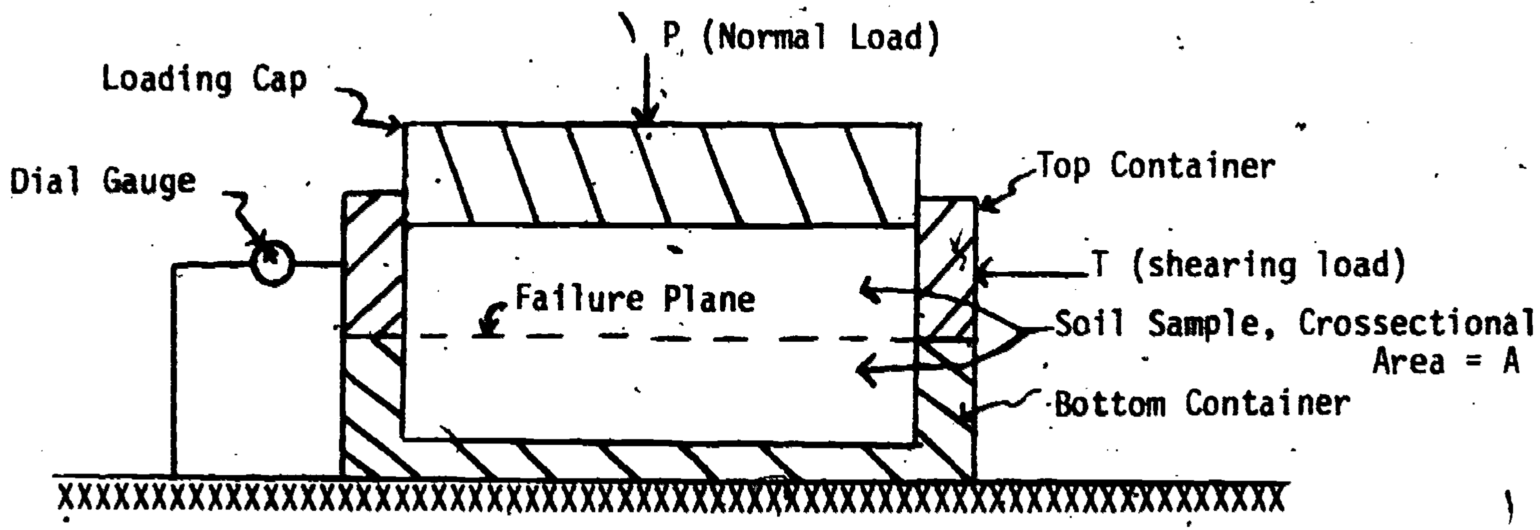
   b. Direct shear testing and triaxial compression testing are most frequently performed.

   c. Direct Shear Test

      i. General description

         -Rectangular or cylindrical soil specimens
         -Disturbed or undisturbed soils tested
         -Split container device

      ii. Experimental setup
         -Sketch



-Loads applied through loading frame

-Dial gauge measures the shearing displacement of the top container relative to the bottom container

-Stresses on the potential failure plane

$$\tau = T/A'$$

$$\sigma_n = P/A$$

iii. Test procedure

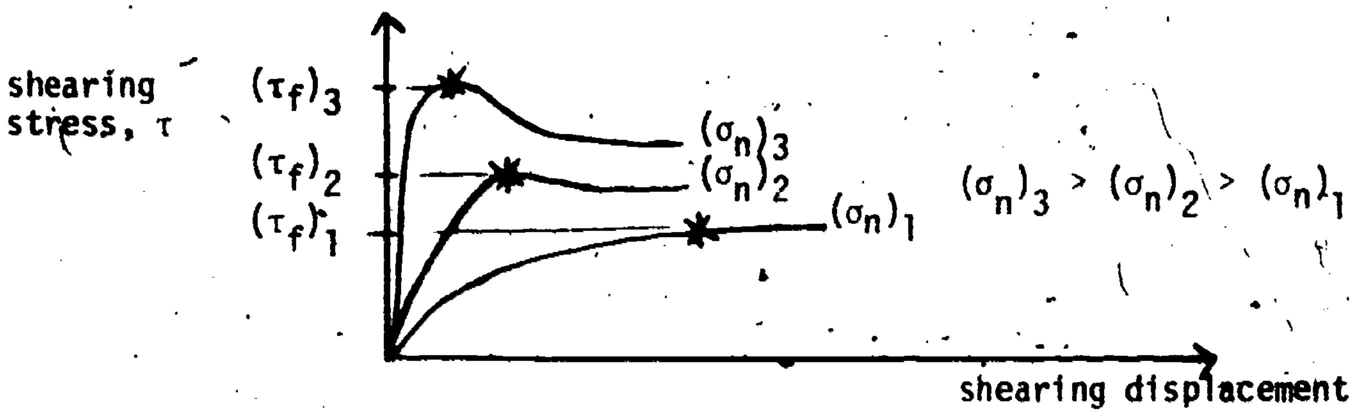
- Prepare a sample of the soil
- Setup the equipment
- Apply the full normal load to the specimen
- Make the initial specimen measurements
- Gradually increase the shearing force acting on the specimen while recording the shearing displacement produced

--- Repeat the entire process but utilize different normal loads in successive tests. In general, a minimum of two tests must be performed to determine the soil cohesion and angle of internal friction but additional tests are desirable.

iv. Data reduction

- Shearing stress applied versus shearing displacement

- One curve for each test performed. Normal stresses applied differ.

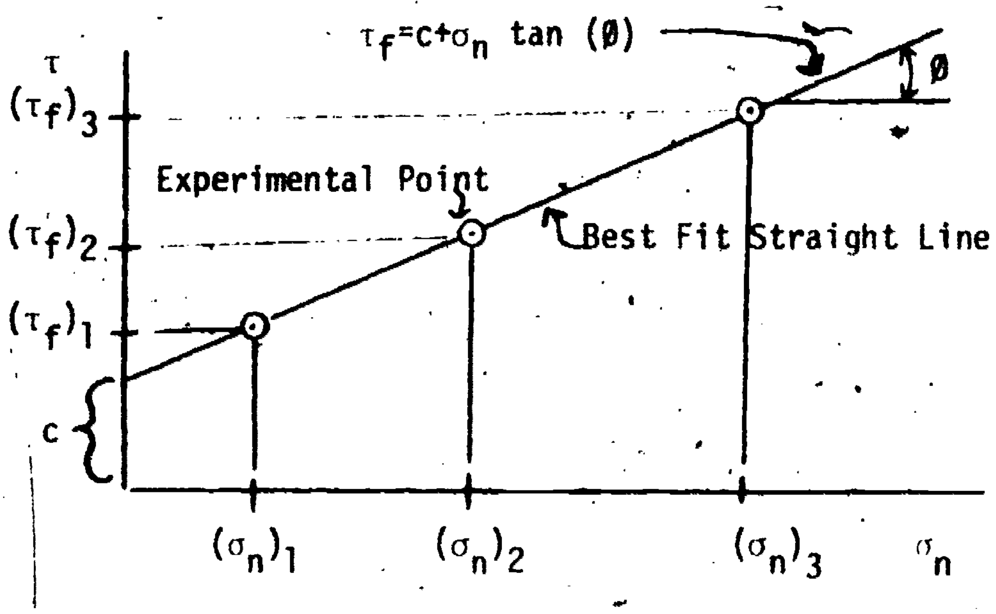


Determine the failure shearing stress for each test from the plots.

- Mohr-Coulomb Theory

$$\tau_f = c + \sigma_n \tan \phi$$

- Plot data $(\tau_f \text{ vs. } \sigma_n)_i$ on $\tau$ vs. $\sigma_n$ axis and read off c and $\phi$.



- Special Case #1

Clean sands c = 0

$\tau_f = \overset{0}{\cancel{c}} + \sigma_n \tan \phi = \sigma_n \tan \phi$

$\phi = \tan^{-1} (\tau_f/\sigma_n)$

- Special Case #2

Saturated clay loaded rapidly $\phi = 0$

$\tau_f = c + \sigma_n \overset{0}{\cancel{\tan}} (\phi) = c$

$c = \tau_f$

v. Accuracy of the test

- Theoretically the test is not very accurate
- Practically, the test produces reasonable values for c and $\phi$ but does not yield good stress-strain relationships in general

vi. Example problem [Direct Shear Test]

Given:
- Crossectional area of specimen = 5 in$^2$
- Loads applied and shearing displacement measurement

| Test No. 1<br>Normal Force, N=100 lbs. | | Test No. 2<br>Normal Force, N = 200 lbs | | Test No. 3<br>Normal Force, N=300 lbs. | |
|---|---|---|---|---|---|
| Shearing Force, T (lbs.) | Shearing Displacement (in.) | Shearing Force, T (lbs.) | Shearing Displacement (in) | Shearing Force, T (lbs) | Shearing Displacement (in) |
| 0. | 0. | 0. | 0. | 0. | 0. |
| 180 | 0.5 | 190 | 0.03 | 320 | 0.02 |
| 300 | 0.1 | 310 | 0 06 | 500 | 0.04 |
| 390 | 0.15 | 405 | 0.09 | 595 | 0.06 |
| 460 | 0.2 | 480 | 0.12 | 650 | 0.08 |
| 510 | 0.25 | 540 | 0.15 | 630 | 0.10 |
| 540 | 0.3 | 585 | 0.18 | 615 | 0.12 |
| 548 | 0.35 | 600 | 0.21 | 605 | 0.14 |
| 552 | 0.4 | 590 | 0.24 | 600 | 0.16 |
| 550 | 0.45 | 575 | 0.27 | | |
| 553 | 0.5 | 574 | 0.3 | | |

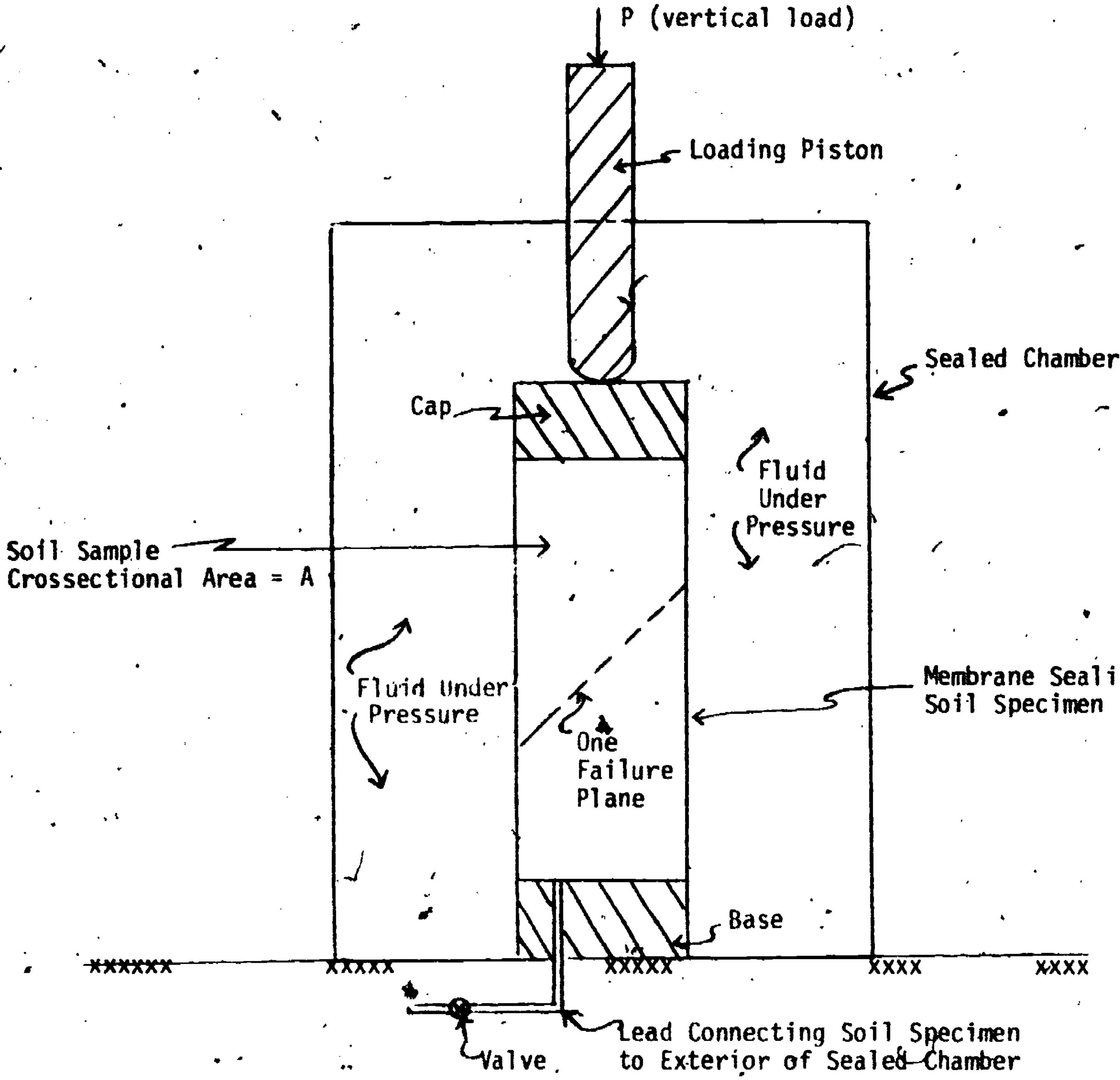
Find: - ~~Soil~~ cohesion, c
- Soil angle of internal friction, $\phi$

### d. Triaxial Compression Test

#### i. General description

- -Cylindrical soil specimens (L/D≈2.5)
- -Disturbed and undisturbed soils tested
- -Provisions for applying independent normal stresses both to the top and sides of the soil specimen
- -Provisions for preventing drainage of fluid from the soil specimen during testing

#### ii. Experimental setup



- Vertical load applied through loading frame
- A dial gauge not shown is placed to record vertical soil sample deflections
- Stresses acting on the soil specimen:

  $\sigma_h = \sigma_c$ = pressure in fluid contained in chamber

  $\sigma_v = P/A + \sigma_c$

  $\sigma_d$ = deviator stress = $\sigma_v - \sigma_h = P/A$

iii. Test procedure

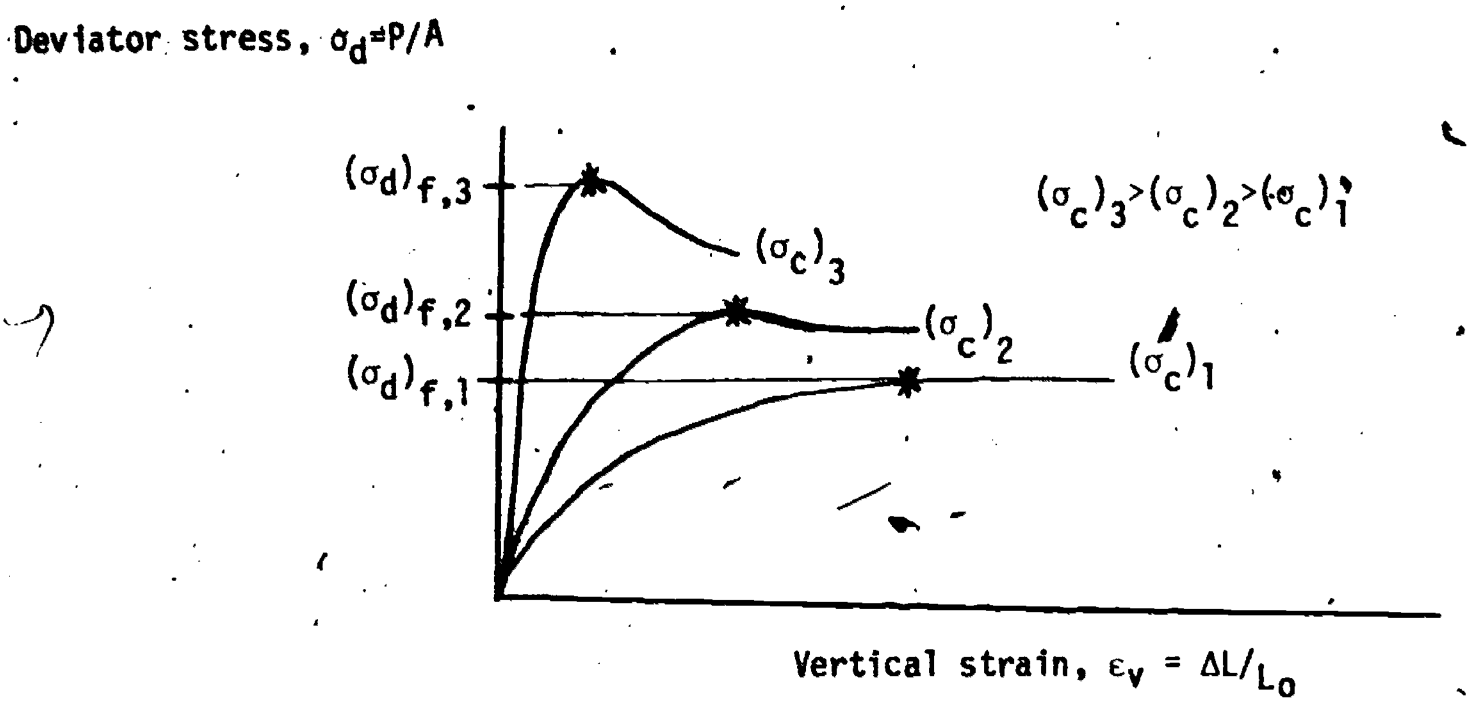
- Test procedure will vary according to the type of triaxial compression test being performed in that the valve shown allowing drainage of fluid from the soil specimen may or may not be open at various times during the test. A general testing sequence is presented.
- Prepare the sample of soil and mount it between the base and the cap. Place and seal the membrane.
- Make the initial sample measurements.
- Set up the equipment.
- Apply a pressure to the fluid in the sealed chamber.
- Gradually increase the vertical load acting on the specimen while recording the vertical deflection produced.

--- Repeat the entire process but utilize different chamber fluid pressures in successive tests. In general, a minimum of two tests must be performed to determine the soil cohesion and angle of internal friction but additional tests are desirable.

iv. Data reduction

- Deviator stress versus vertical strain

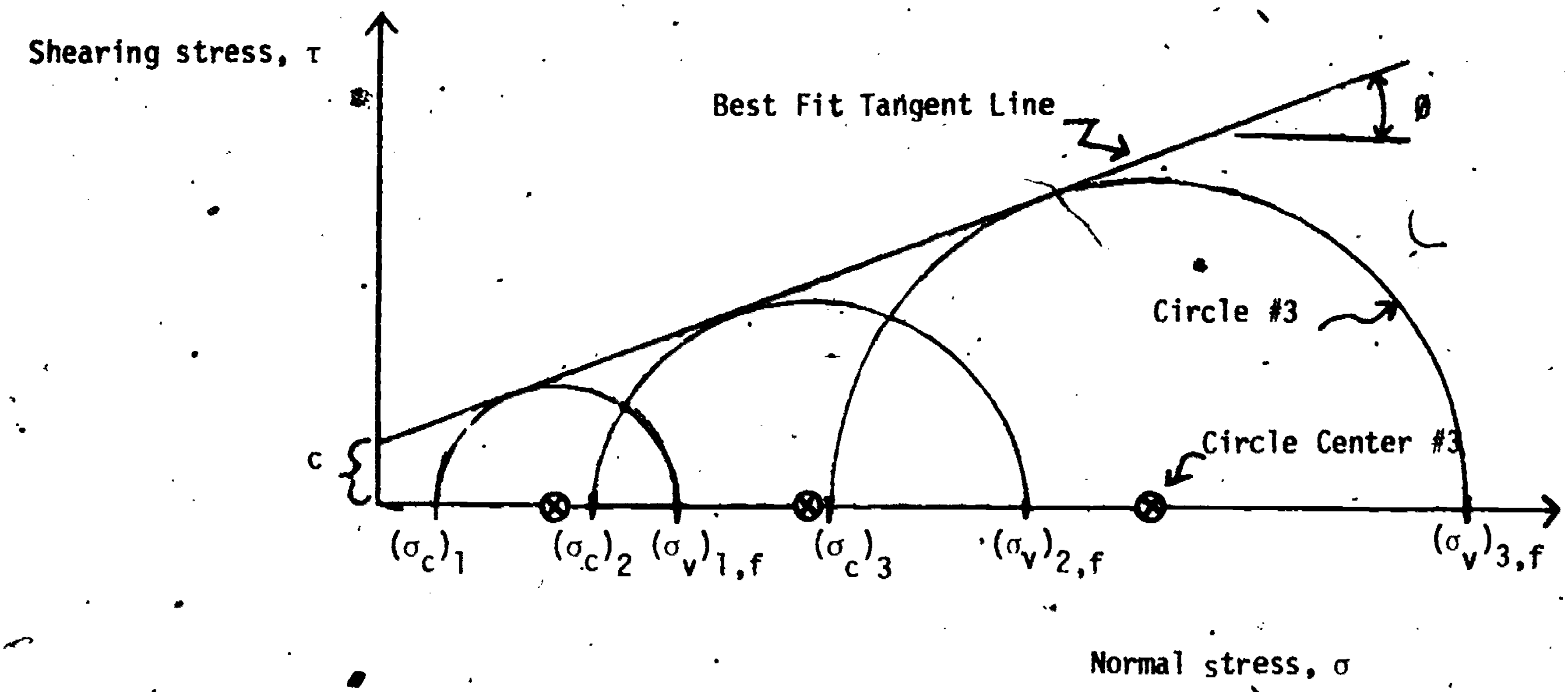
  One curve for each test performed. Horizontal stresses applied differ.



Vertical strain equals the change in the specimen length, $\Delta L$, divided by its initial length $L_o$.

Determine the failure deviator stress for each test from the plots.

- Based on the Mohr-Coulomb Strength Theory and Mohr's circles for representing the stresses acting in any body, the following construction can be made.



Construct a $\tau$ vs. $\sigma$ axis utilizing the same scale on the ordinate and the abcissa.

Plot points corresponding to $\sigma_c$ and $(\sigma_v)_f$ for each test performed on the normal stress axis. [Note $(\sigma_v)_f = (\sigma_d)_f + \sigma_c$].

Construct a circle passing through both points for each test and having a center lying on the normal stress axis.

Construct a best fit line tangent to the circles constructed.

Read off the soil cohesion and angle of internal friction as shown:

An equation could also be written and c & $\phi$ could be determined from this equation.

$$(\sigma_v)_f = \sigma_c\left(\frac{1 + \sin\phi}{1 - \sin\phi}\right) + 2c\,\frac{\cos\phi}{1 - \sin\phi}$$

where: $(\sigma_v)_f$ = vertical stress applied at failure for test
$\sigma_c$ = chamber fluid pressure for test
$\phi$ = soil angle of internal friction
c = soil cohesion

Note: Failure will occur on some inclined plane or planes in the soil sample. Identifying the potential failure plane is more complex in this test than in the direct shear test.

- Special Case #1

Clean sands c = 0

$$(\sigma_v)_f = \sigma_c\left(\frac{1 + \sin\phi}{1 - \sin\phi}\right) + 2\overset{0}{\cancel{c}}\,\frac{\cos\phi}{1 - \sin\phi} = \left(\frac{1 + \sin\phi}{1 - \sin\phi}\right)\sigma_c$$

$$\left(\frac{1 + \sin\phi}{1 - \sin\phi}\right) = \tan^2(45 + \phi/2) = \frac{(\sigma_v)_f}{\sigma_c}$$

$$\phi = 2\tan^{-1}\left[\sqrt{(\sigma_v)_f/\sigma_c}\,\right] - 90°$$

- Special Case #2

saturated clay loaded rapidly (undrained) $\phi = 0$

$$(\sigma_v)_f = \sigma_c\left(\frac{1 + \sin\phi}{1 - \sin\phi}\right) + 2\,c\,\frac{\cos\phi}{1 - \sin\phi} = \sigma_c + 2c$$

$$c = \frac{(\sigma_v)_f - \sigma_c}{2} = \frac{(\sigma_d)_f}{2}$$

### v. Specific Types of Triaxial Compression Tests

- Consolidated Undrained

- Consolidated Drained

- Unconsolidated Undrained

- Unconsolidated Drained

- Primary difference between tests lies in when if at all fluid is allowed to drain from the soil specimen.

- The test performed is selected on the basis of how accurately it simulates field conditions. (Examples).

### vi. Effective Stresses versus Total Stresses.

- All the stresses in this discussion of soil stress-strain and strength characteristics could be expressed in terms of either effective stresses or total stresses.

- Effective stresses are the correct stresses because it has been shown that they best describe soil behavior.

- Total stresses are frequently used, however, due to the difficulty in determining pore water pressures.

- Soil cohesion and angle of internal friction values determined using total stresses are denoted by: $c$ ; $\phi$.

- Soil cohesion and angle of internal friction values determined using effective stresses are denoted by: $c'$ ; $\phi'$.

### vii. Unconfined Compression Test

- A special case of the Unconsolidated Undrained triaxial compression test.

- Work in terms of total stresses.

- Test most frequently performed on saturated clay and since the test is an undrained test, $\phi = 0$.

$$(\sigma_v)_f = \sigma_c\left(\frac{1 + \sin\phi}{1 - \sin\phi}\right) + 2c\,\frac{\cos\phi}{1 - \sin\phi} = \sigma_c + 2c$$

$$c = \frac{(\sigma_v)_f - \sigma_c}{2}$$

- Circumferential area of the specimen is exposed to the atmosphere and $\sigma_c = 0$. [Always work in terms of gauge pressure].

$$c = \frac{(\sigma_v)_f}{2} = \frac{q_u}{2}$$

where: $(\sigma_v)_f$ = vertical stress applied to sample at failure= $q_u$
$q_u$ = unconfined compressive strength
$c$ = soil cohesion

- Very quick test to perform and a very popular test in practice

- Occasionally performed on other than saturated clays because it will generally yield conservative values for design but care should be taken in the analysis

- Example Problem: [Unconfined Compression Test]

Given: Initial sample crossectional area = 6 $in^2$
Initial sample length = 3.5 in

Vertical Load Versus Vertical Deflection

| Vertical Load, P (lbs.) | Vertical Deflection, ΔL (in.) |
|---|---|
| 0 | 0 |
| 20 | .05 |
| 32 | .1 |
| 39 | .15 |
| 42 | .20 |
| 41 | .25 |
| 39.5 | .30 |
| 38 | .35 |
| 38 | .40 |
| 37.5 | .45 |
| 37 | .5 |
| 37.5 | .55 |

Soil is a saturated clay

Find: Vertical stress versus vertical strain curve (illustrate area correction)

$(\sigma_v)_f$

$q_u$

$c$

viii. Accuracy of triaxial compression testing

- Most accurate of commonly used soil stress-strain and strength tests
- Some theoretical problems, however.

4. Primary factors affecting the cohesion and angle of internal friction of one soil.

   a. Density

   b. Fluid pressure within the soil voids

   c. Disturbance and alteration

5. Typical values for the cohesion and angle of internal friction of various soils.

   a. Table

| Soil Type | $\phi$ (Degrees) | c (psf) |
|---|---|---|
| Clean Sand | 25-50 | ~ 0 |
| Silt | intermediate | |
| Clay | 0-40 | 0-2500 |

   b. In general, soils exhibit a wide range in values for these properties.

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411
Week No.: 8

OUTLINE OF WEEKLY LECTURE NOTES

Prepared by: J. B. Thompson
Date: 11/5/73

Lecture Subjects: Field Investigations, Engineered Fills, Seepage Through Soils

Assignment: Read - pp. 59-72, 78-86, 492-505, 517-527, 529-570, 606-616
Problems - To be assigned

## Presentation

I. Field Investigations

  A. Purposes:

    1. Gain general knowledge of proposed site(s)

    2. Determine the distribution and characteristics of the soil present at the proposed site(s)

    3. Locate and describe the groundwater present at the proposed site(s).

  B. Composition of field investigations

    1. Making general observations

    2. Penetrating the soil deposit

    3. Sampling the soil deposit

    4. Performing field tests on the soil deposit

  C. General observations

    1. Climatic conditions

    2. Topography

    3. Surface water

    4. Past slope failures and resulting scars

    5. Surrounding structures

    6. History of the area (e.g., seismicity, flooding, mining, oil or gas production, soil swell, soil frost action, etc.)

  D. Penetrating the soil deposit

    1. Hand auger

    2. Backhoe

    3. Chopping bit

4. Mechanical auger
5. Rotary wash
6. Bucket rig
7. Cable-Tool rig

E. Sampling the soil deposit
1. Block sample
2. Split spoon sample
3. Shelby tube sample
4. Piston sample
5. Foil sample
6. Core barrel sample
7. Frozen sample

F. Field testing of the soil deposit
1. Standard Penetration Test
2. Cone Penetration Test
3. Permeability Test
4. Borehole Shear Strength Test
5. Borehole Expansion Stress-Strain Properties Test
6. Vane Shear Test
7. Plate Load Test
8. Pile Load Test
9. Test for Locating the Groundwater Table

G. Design of field exploration programs
1. Each field exploration program will be different.
2. Design based on:
   a. Type of project
   b. Distribution and magnitude of loads
   c. Anticipated conditions at proposed site
   d. Regulations established by owner or regulatory agency

3. Examples
    a. Highway construction
    b. Shallow foundations
    c. Pile foundations
    d. Dam construction

H. Summarizing the results of the field exploration program
    a. Boring logs or logs of pits excavated
    b. Summary sheets of field tests
    c. Soil profiles

II. Design and Construction Problems Dealing with Soil (Emphasize Construction Problems)

A. Topics to be discussed include

1. Engineered fills
2. Seepage through soils
3. Retaining structures
4. Foundations
5. Slopes
6. Dams and reservoirs
7. Subgrades

B. Each topic will be briefly presented

C. Engineered fills

1. Definition
    a. Engineered fills are man deposited soil masses designed to have certain properties and whose construction is controlled to assure that these desired properties are achieved.

2. Utilization
    a. Engineered fills are frequently designed and constructed to act as:
        i. Water retaining structures (e.g. dams and levees)
        ii. Backfill behind or over various structures (e.g. retaining walls, pipelines)
        iii. Highway and airfield subgrades
        iv. Surcharges to preload soil deposits

   v. Structural foundation material having a high strength and a low compressibility.
   vi. Material to achieve the desired site grade

3. Design and specification of engineered fills

   a. See previous discussion on soil compaction

4. Construction of engineered fills

   a. General process

      i. Fill is constructed in lifts (layers)
      ii. Soil is obtained from some borrow area(s) and modified if necessary (e.g. graded, mixed with other soil)
      iii. The desired compaction moisture content is achieved in the soil
      iv. Soil is placed in location in an uncompacted condition until the desired lift height is achieved
      v. Soil is compacted to the desired $\gamma_d$

   b. Locating soil borrow area

      i. Major problem in some cases
      ii. Must know first what type of soil must be acquired
      iii. Air photos sometimes helpful

   c. Obtaining the desired moisture content

      i. Conveyor system with dryer or a sprayer depending on which is needed is most convenient
      ii. Frequently water truck or hose techniques are used to add water
      iii. Drying soil is a major problem particularly in heavy rainfall regions

   d. Lift heights

      i. In general, an increase in the lift height will result in an increase in the number of passes a given compactor will have to make to achieve the desired degree of compaction
      ii. Economic trade offs are important
      iii. If the lift is too thick, it will be impossible to achieve the desired degree of compaction

   e. Compaction of the soil

      i. Compaction of the soil is achieved by the passage of a piece of compaction equipment over the soil
      ii. Static compaction equipment
         - Smooth-wheel roller
         - Sheepsfoot roller
         - Rubber-tired roller
      iii. Vibratory compaction equipment
         - Smooth-wheel vibratory roller
         - Vibratory sheepsfoot roller
         - Rubber-tired vibratory roller

iv. Tampers and vibrators
v. Vibroflotation
vi. Compaction piles
vii. In general, the fined grained soils compact best under static compaction equipment.
viii. In general, the coarse grained soils compact best under the vibratory compaction equipment

5. Control of the construction of engineered fills

a. In general, check that the required dry density is achieved

b. Occasionally must also assure that the desired water content is being utilized

c. Water content check

i. Obtain a sample of the compacted soil immediately after placement and perform a standard water content test using equipment designed for field applications.
ii. As a replacement to the standard water content test, a Speedy Moisture Meter or Nuclear Moisture Density Meter determination might be performed as those two testing techniques considerably reduce the time required. [Note: These substitutes are not always accurate and should be used with care].
iii. Compare water content measured to the desired value(s)

d. Dry density check

i. Utilize following equation:

$$\gamma_d = \frac{\gamma}{1+w}$$

where: $\gamma_d$ = soil dry density
$\gamma$ = soil bulk density
$w$ = soil water content

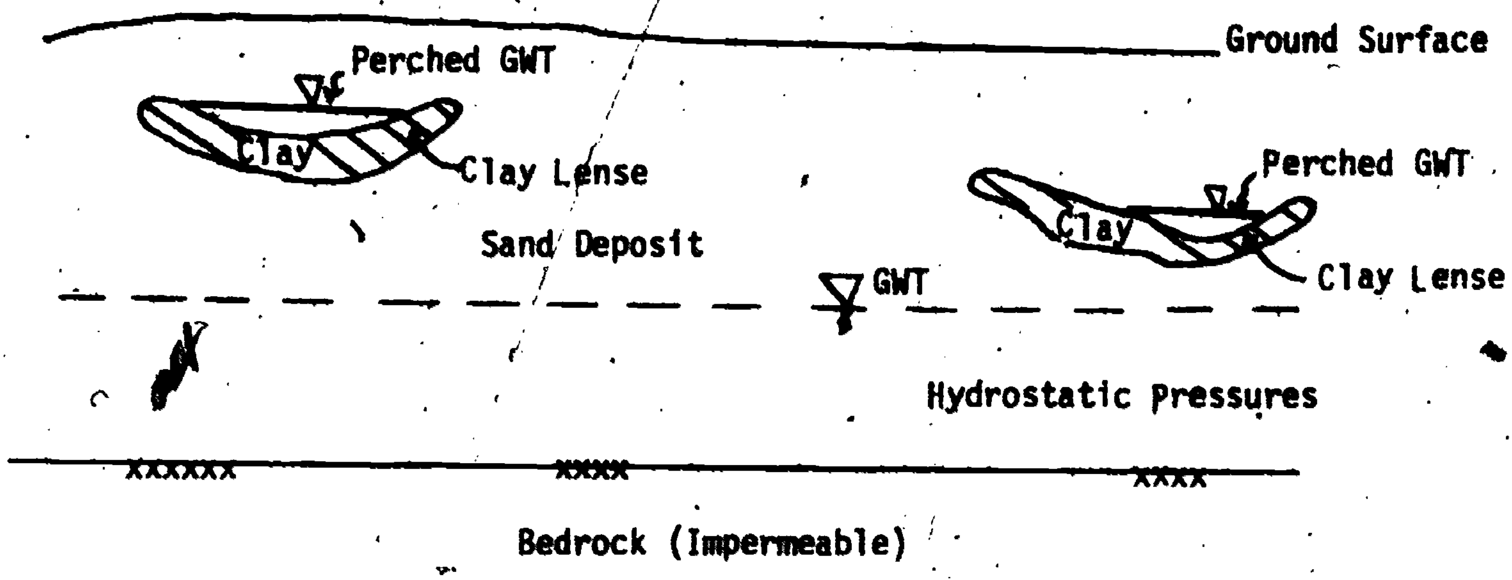
ii. Water content, w, determined as indicated above
iii. Soil bulk density determined by excavating and weighing a chunk of soil from the compacted fill and determining the volume of the soil removed from the compacted fill by one of the following methods:

- Direct measurement
- Sand cone method
- Rubber balloon method

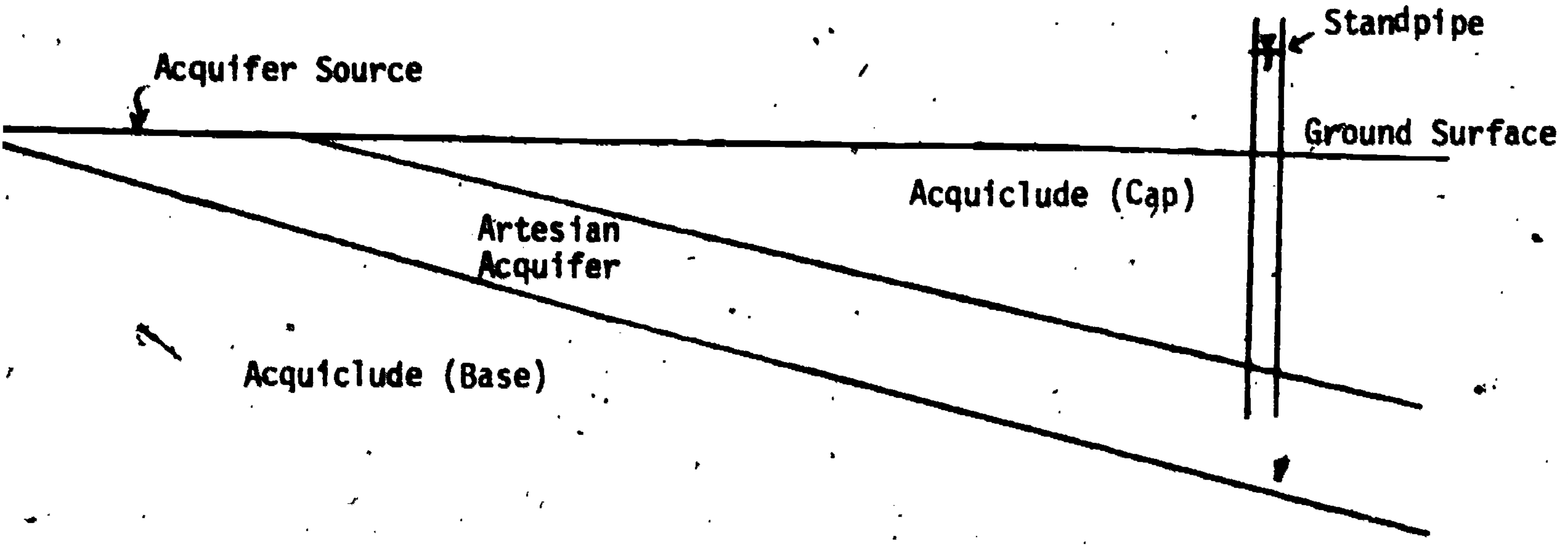
iv. Alternatively, the bulk density may be determined by using the Nuclear Moisture Density Meter although care must be taken due to inaccuracies which will result in some cases.
v. Compare the computed soil $\gamma_d$ as compacted with the desired value(s).

6. Problems which may develop in the construction of engineered fills
    a. Inability to meet specifications
    b. Delays due to inspection requirements
    c. Mobility of vehicles
    d. Mud waves
    e. Erosion or overtopping of fills near bodies of water
7. Hydraulic fills

D. Seepage through soils
1. Commonly encountered groundwater conditions in soil deposits
    a. Single groundwater table hydrostatic pressure conditions
    b. Perched groundwater tables hydrostatic pressure conditions
        i. Sketch



        ii. Identifying perched GWT's
            - Loss of drilling water
            - Identification of profile
            - Knowledge of principle GWT location at site
    c. Artesian conditions
        i. Sketch



ii. Water will rise in standpipe placed in the artesian acquifer above the GWT

d. Capillary rise conditions

   i. Water pressures less than atmospheric
   ii. Water encountered above the groundwater table
   iii. Completely saturated zone and partially saturated zone

e. Evapotranspiration

2. Primary problem areas involving seepage of water through soils

   a. Computation of and control of the quantity of water seepage through soils

   b. Computation of and control of possible soil erosion and instability due to the seepage of water through soil

3. Theory of seepage of water through soils

   a. Seepage of water through soils can be described by a partial differential equation formulated from:

      i. Continuity equations
      ii. Darcy's Law

   b. Equation

$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial y^2} + k_z \frac{\partial^2 h}{\partial z^2} = 0$$

   c. Certain assumptions are necessary to establish the above equation

4. Solution of this basic partial differential equation

   a. Can be solved exactly or nearly exactly in a very few restricted cases (see section on soil permeability)

b. In most cases, must be solved approximately

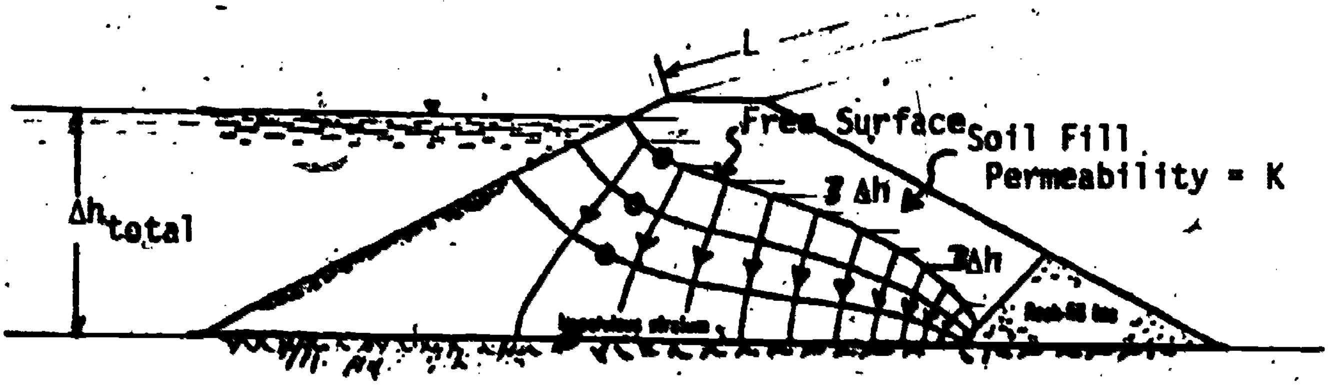
   i. Graphical solution (flow net)
   ii. Mathematical analogs
   iii. Electrical circuit analogs
   iv. Resistivity paper
   v. Models

c. Graphical solutions (flow nets) are the most frequently used and will be discussed here.

5. Flow nets

   a. Graphical solution to the controlling differential equation and as such must have certain characteristics

   b. Example flow net (Homogeneous Earth Dam)



HOMOGENEOUS EARTH DAM

Legend: O Streamline
V Equipotential Line

   c. Will deal with flow nets for two dimensional flow in homogeneous, isotropic soil

   d. Composition of a flow net

      i. Streamlines (flow lines)
         - Indicates path water flows

      ii. Equipotential lines
         - Lines of equal water head

   e. Requirements of a correctly drawn flow net

      i. Streamlines and equipotential lines must always intersect at right angles
      ii. The average side dimensions along streamline and equipotential line directions of an area in a net bounded by two equipotential lines and two streamlines should be equal if possible. Otherwise the dimensions should be of the same ratio as all other

areas bounded by the two equipotential lines.

iii. If a free surface (phreatic surface) exists in the flow net, the vertical distance between the intersection of adjacent equipotential lines and the free surface should be a constant.

f. Drawing a flow net is a trial and error procedure,

g. Computing the quantity of seepage from a flow net

i. Theory yields an equation:

$$Q = \frac{N_F}{N_D} \Delta h_{total} \ k \ L$$

where: $Q$ = volumetric rate of flow through the flow net (cfs)
$N_F$= number of flow tubes (number of flow lines minus one)
$N_D$= number of equipotential drops
$N$ = soil permeability
$k$ = length of structure (distance into paper)
$\Delta h_{total}$ = total head loss through the flow net

ii. $N_D$

- if all areas are perfect "squares," $N_D$ = number of equipotential lines minus one
- if all areas are not perfect squares, $N_D$ = number of perfect squares plus the sum of the ratios of the side dimensions of the non-square areas. The ratio to be used is the dimension measured in the equipotential line direction divided by the dimension measured in the streamline direction.

h. Determining the likelihood of possible soil erosion and instability from a flow net

i. A number of sophisticated methods of analysis

ii. Will examine the critical hydraulic gradient concept which is a general indicator of possible problems

iii. Critical hydraulic gradient, $i_{cr}$

- Equation

$$i_{cr} = \frac{\gamma - \gamma_w}{\gamma_w} = \frac{\gamma_b}{\gamma_w}$$

where: $i_{cr}$ = critical hydraulic gradient

$\gamma$ = soil bulk unit weight (usually $\gamma_{sat}$)

$\gamma_w$ = unit weight of water

$\gamma_b$ = soil buoyant unit weight

- Typical values

$\gamma = 120 \qquad \gamma_w = 62.4$

$$i_{cr} = \frac{120-62.4}{62.4} = \frac{57.6}{62.4} \simeq 1$$

iv. If the critical hydraulic gradient is exceeded at any point in the flow net at which the flow has an upwards component, then erosion or instability of the soil deposit is possible. Erosion will result if this condition develops at or near the surface.

v. Computation of hydraulic gradients at points in the flow net

- Equation

$$\text{Hydraulic gradient} = i = \frac{\Delta h}{\ell}$$

where: $\Delta h$ = some head loss
$\ell$ = length over which head loss occurs

- Hydraulic gradient is different at different points

- $\Delta h$

Computed between two equipotential lines

For all perfect "square" areas, $\Delta h = \Delta h\ \text{total}/N_D$

For non-perfect "square" areas, $\Delta h$ = $\Delta h$ total/(ratio of sides). The ratio of the sides is the same ratio discussed earlier.

- $\ell$

Distance between two equipotential lines along water flow path measured from flow net and scaled appropriately

vi. Summary

- If flow has an upwards component and:

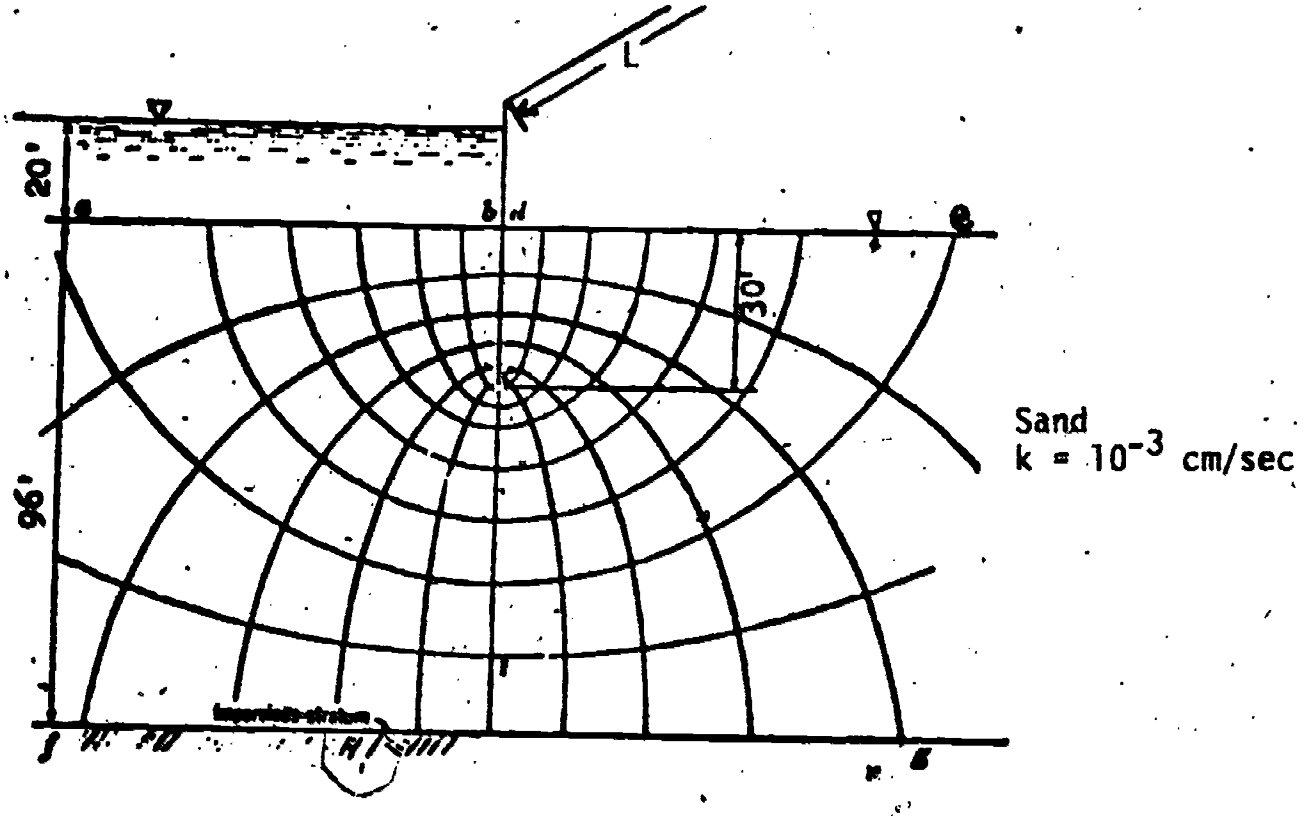
$i \geq i_{cr}$ erosion and instability may occur

$i < i_{cr}$ erosion and instability are not likely

- Must check all points in the flow net. Highest hydraulic gradients will occur where the equipotential lines are closely spaced.

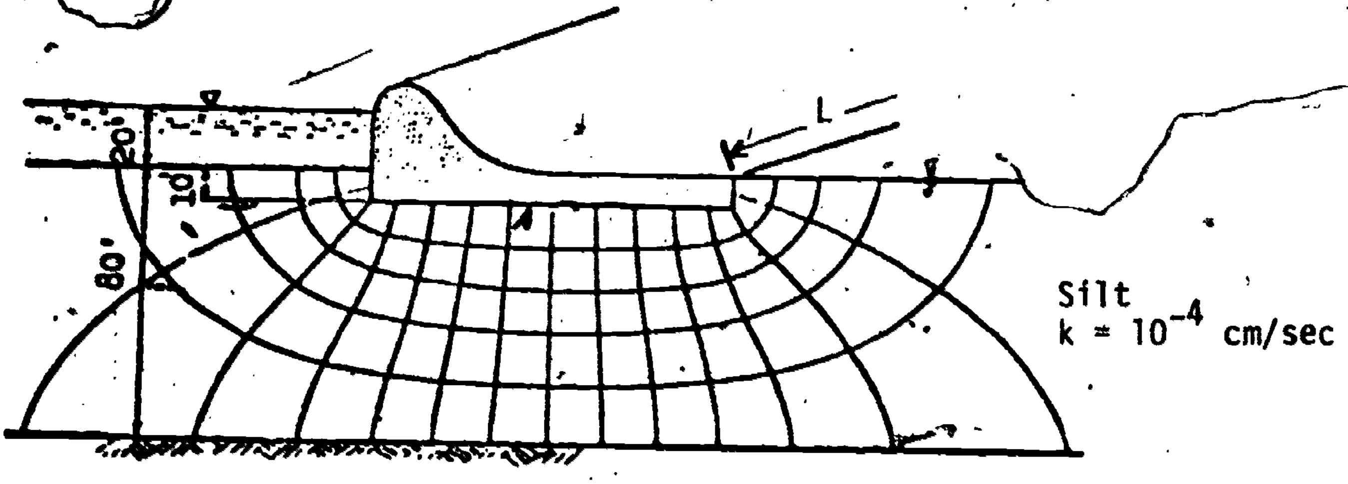
i. Example flow nets, seepage quantity calculations, and erosion and instability checks.

ample 1



SHEET PILE COFFERDAM

ample 2



MASONRY DAM

6. Controlling seepage quantities and erosion and instability possibilities
    - i. Cores
    - ii. Cutoffs
    - iii. Blankets
    - iv. Wells - well points
    - v. Drains
    - vi. Surcharges

7. Construction problems related to seepage through soils
    - i. Dewatering excavations
        - Removing inflow
        - Maintaining a stable excavation base
        - Possible damage to surrounding structures
    - ii. Vehicle mobility
    - iii. Tunneling into water bearing deposits
    - iv. Stability of cut and fill slopes

8. Filters

9. Quicksand

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: [illegible]C 411
Week No.: 9

Outline of Weekly Lecture Notes

Prepared by: J. B. Thompson
Date: 11/5/73

Lecture Subjects: Retaining Structures, Foundations

Assignment: Read - pp. 205-222, 233-250, 296-465, 586-601 (brief parts)

Problems - To be assigned

## Presentation

I. Design and Construction Problems Dealing with Soil (Emphasize Construction Problems) [continued]

A. Retaining Structures

1. Definition

a. An earth retaining structure is any structure designed and constructed to hold back a soil mass.

b. Frequently, this soil mass would be unstable unless otherwise supported.

2. Utilization

a. Retaining structures are generally constructed when economic land use requires steep and/or high soil slopes or when the geometry of a particular job makes them mandatory.

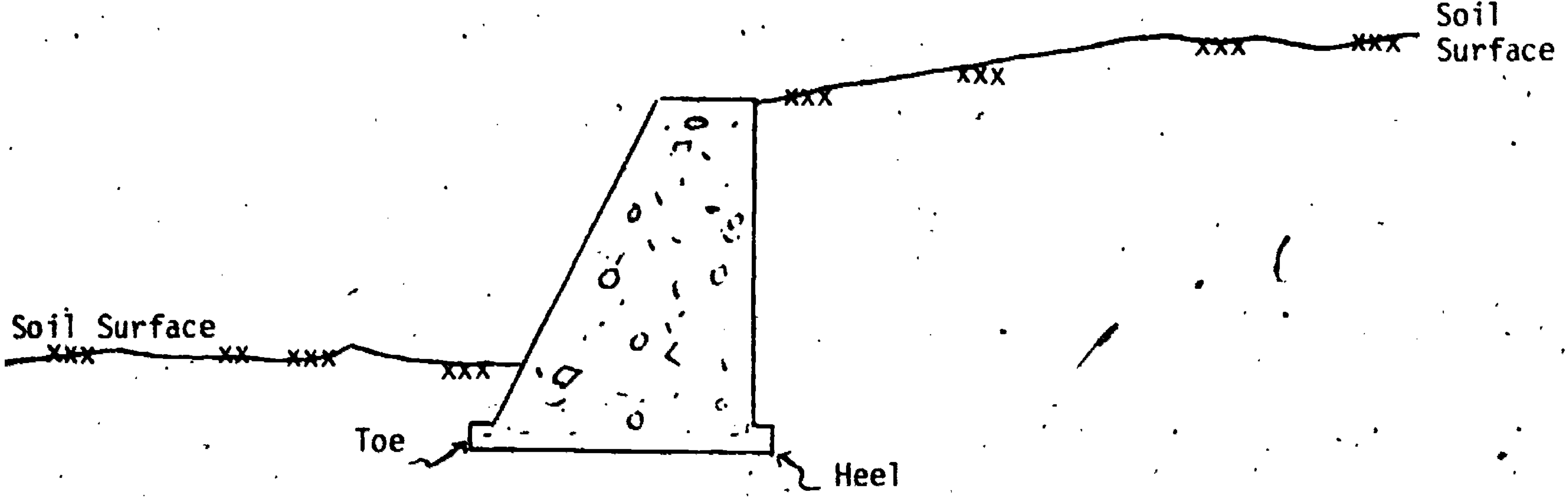
b. Examples:

- i. Highway cuts and fills
- ii. Cuts and fills associated with land development
- iii. Construction excavation (e.g. structural basements)
- iv. Dock structures (e. g. wharves)
- v. Dam construction (e.g. cofferdams)

3. Types of retaining structures

a. Gravity retaining wall

i. Sketch



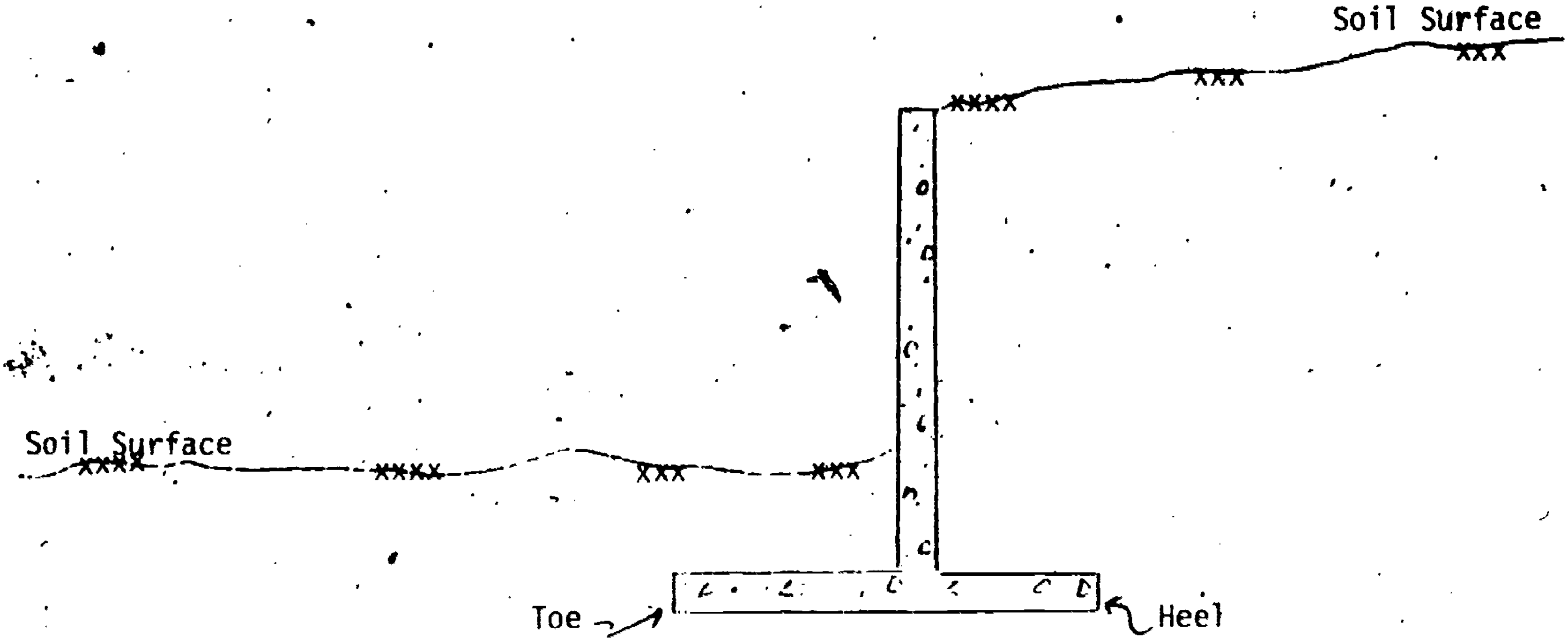
ii. Massive concrete structure

iii. May or may not be reinforced

iv. Stability of the wall results from its own large weight

b. Cantiliver retaining wall

i. Sketch

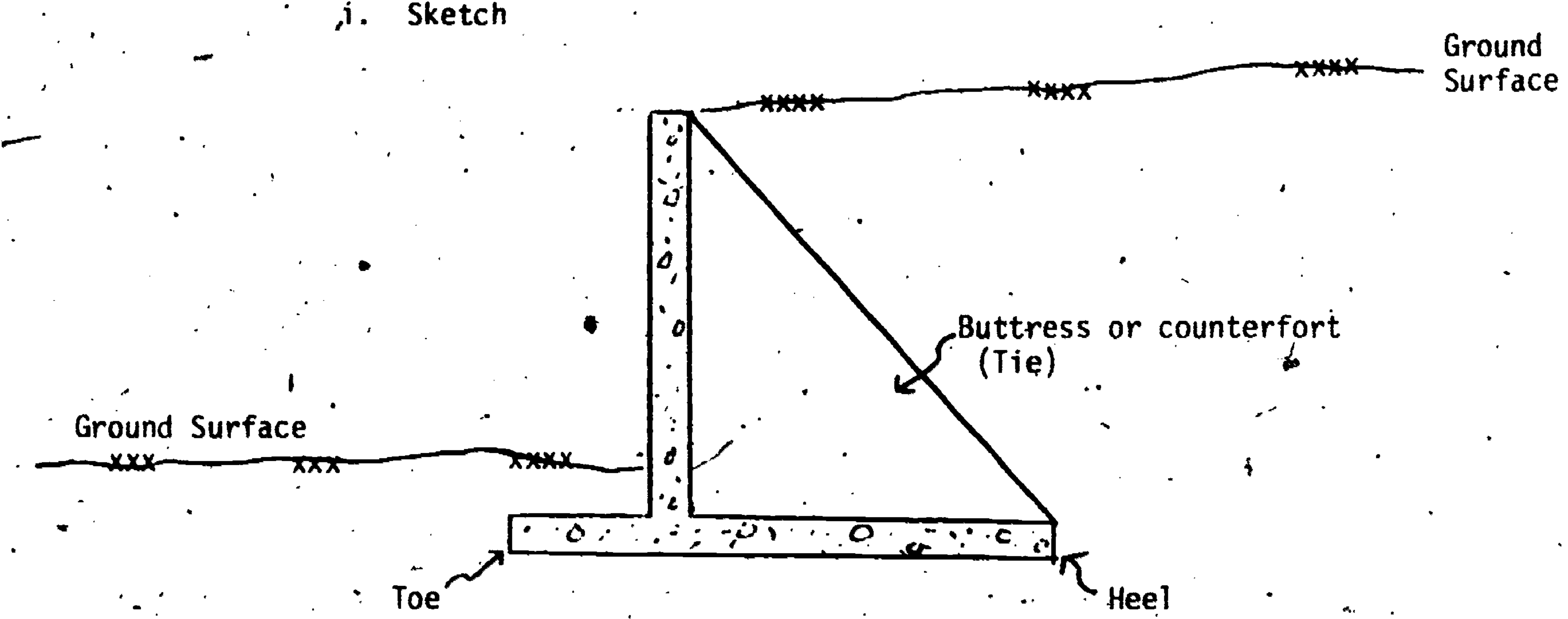


ii. Constructed of reinforced concrete

iii. Stability of the wall results from the soil pressure acting on the wall footing

c. Buttress or counterfort retaining wall

i. Sketch

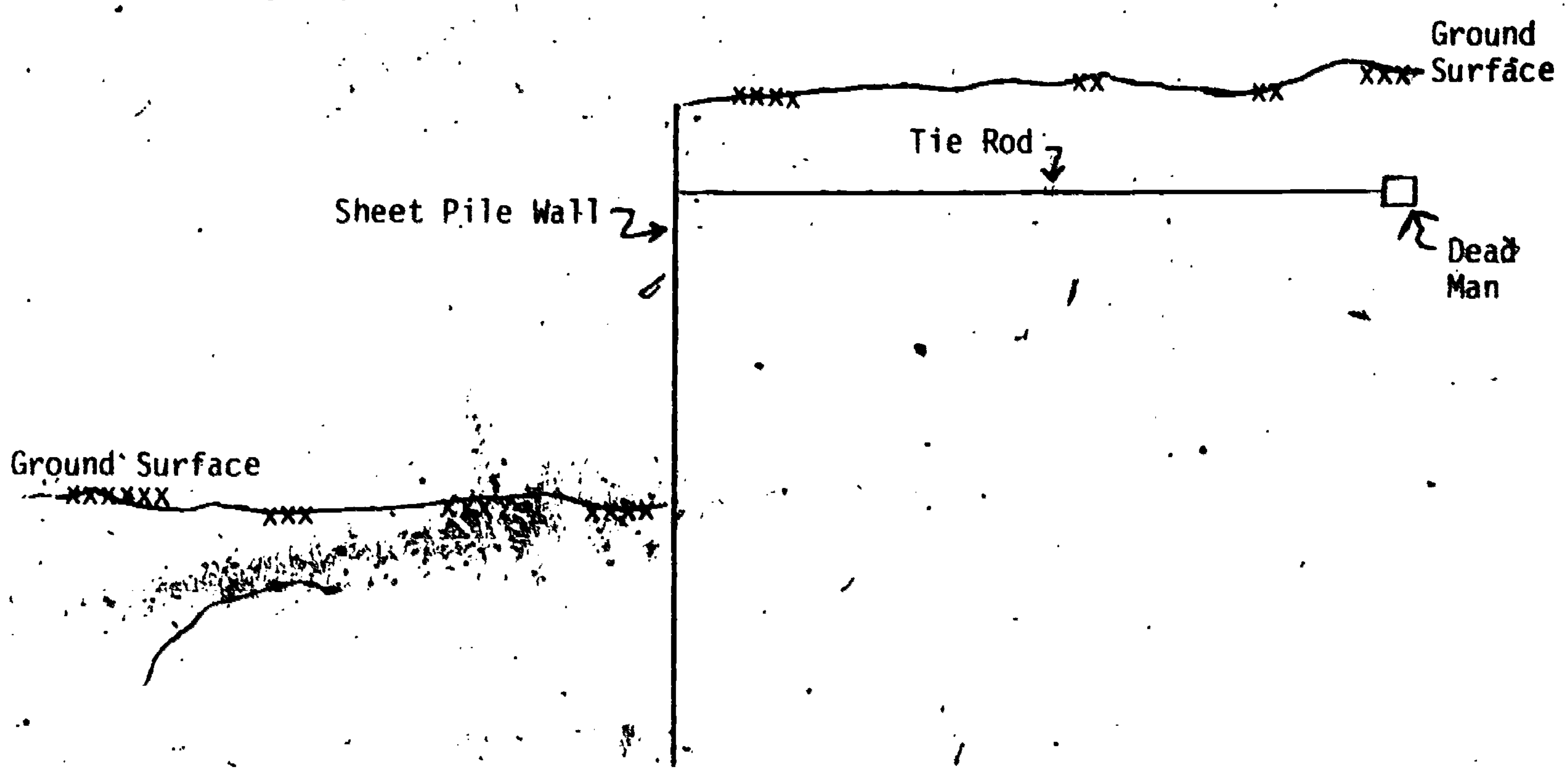


ii. Constructed of reinforced concrete

iii. Stability of the wall results from the soil pressure acting on the wall footing

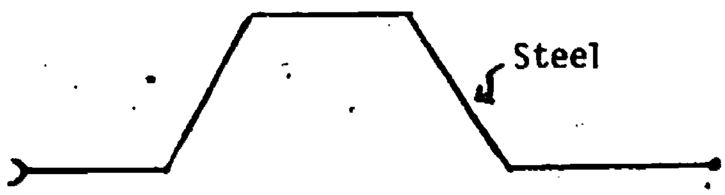
d. Sheet pile retaining wall

i. Sketch



ii. Usually constructed of steel sections

- One typical section



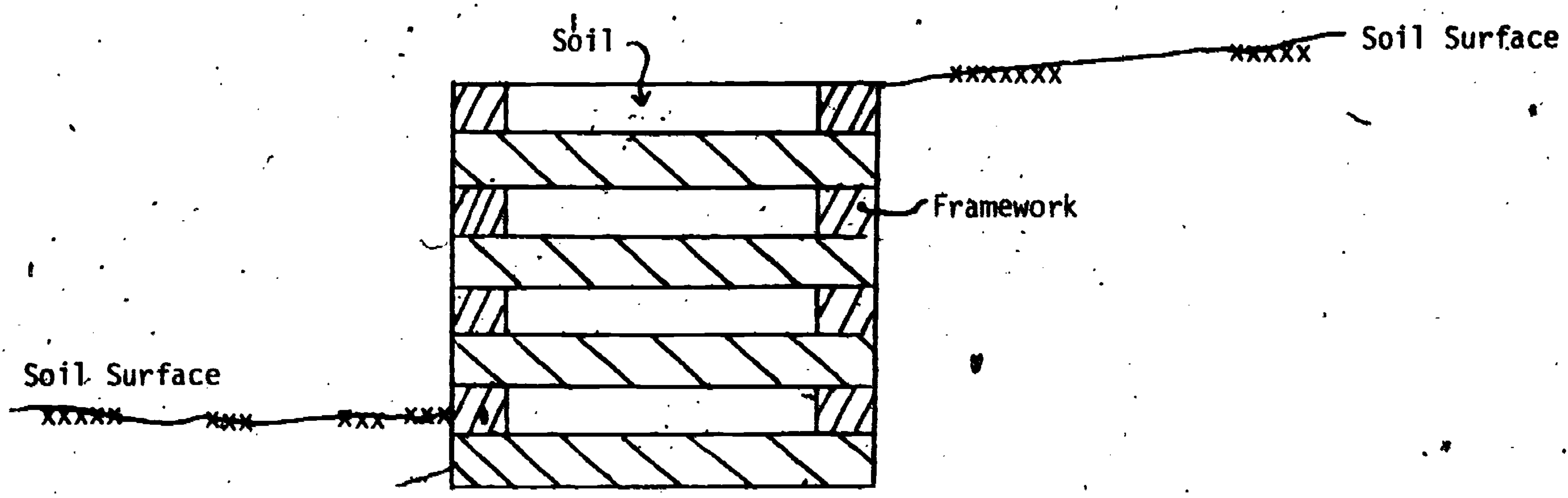
- Frequently tongue and groove connections

iii. Occasionally designed and constructed as a "tie-back" retaining wall utilizing the dead man and the tie rod shown

iv. Stability of the wall results from the soil pressures acting against the completely submerged portion of the wall and the "tie backs" if utilized

e. Crib walls

i. Sketch

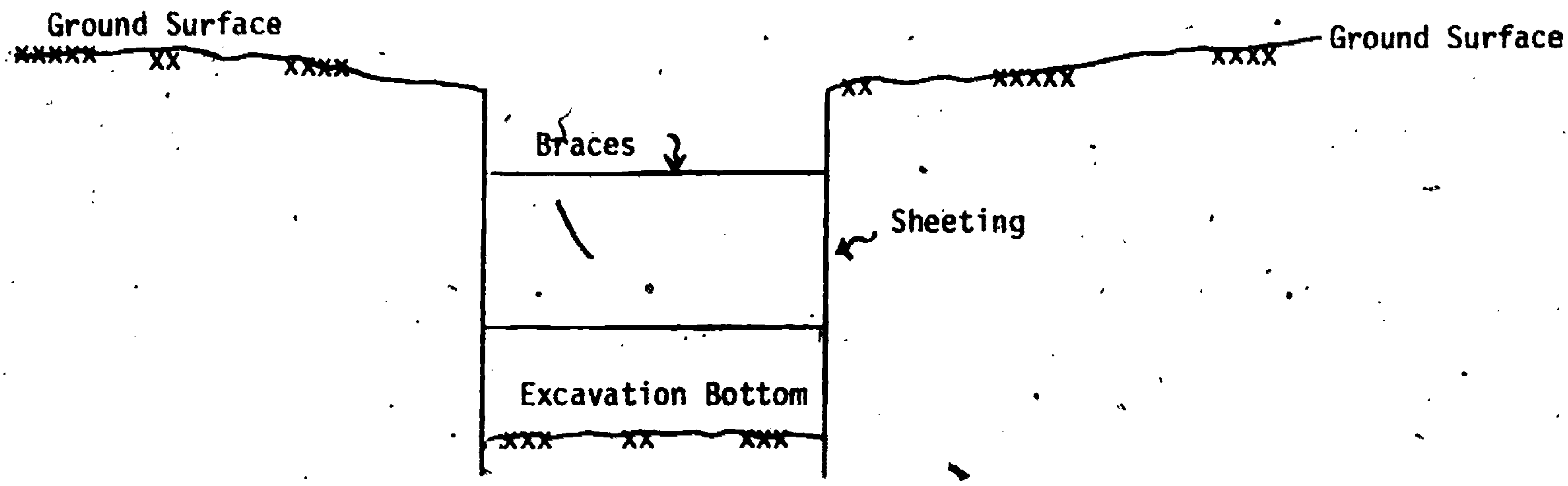


ii. Wood, concrete, or steel framework filled with soil. Material and dimensions of framework highly variable.

iii. Stability of the wall generally results from its own large weight

f. Braced excavations

i. Sketch



ii. Material used could be steel, concrete, or wood

iii. Stability of the excavation provided predominantly by the braces

iv. Configuration of braces variable

g. Soldier beam - lagging design

h. Cofferdams

i. Slurry trenches

j. Reinforced earth

4. General design procedures

   a. The particular design procedure to be followed will vary with the type of retaining structure to be utilized.

   b. General design procedure consists of:

      i. Determining the soil pressures acting on the retaining structure
      ii. Dimensioning the retaining structure
      iii. Checking the stability of the retaining structure
         - Soil bearing capacity
         - Sliding
         - Overturning
         - General slip of entire structure

iv. Calculating the forces, shear stresses and moments generated in the structure by the soil pressures acting on it

v. Performing a structural design
  - Steel sections
  - Concrete sections and reinforcement
  - Timber sections
  - Connections

c. Additional factors which must be considered in the design of retaining structures.

i. Construction procedures
ii. Joints
iii. Drainage of the backfill
iv. Source of the backfill
v. Effects on surrounding structures
vi. Economics
vii. Building Codes

d. A completed design must be accompanied by construction drawings

Notes: a) Earth pressures exerted on retaining structures are highly dependent on the construction sequence followed.

b) The contractor frequently designs the excavation bracing needed for a particular project. Most other retaining structures are designed by other engineers.

5. Aspects of the construction of retaining structures

a. Excavation and possible dewatering
b. Sheet pile driving
c. Concrete and reinforcement placement
d. Bracing placement
e. "Tie-Back" installation
f. Drainage system installation
g. Fill construction

B. Foundations

1. Definition

a. A foundation is a structure designed to transmit a load to some soil deposit.

b. Common sources of the load to be transmitted to the soil deposit include:

i. Weight of structure
ii. Wind forces
iii. Snow forces

iv. Wave forces
v. Weight of cars, trucks and trains
vi. Weight of fluids (e.g. oil)
vii. Soil masses

2. Utilization

a. A foundation must be designed and constructed whenever a load is to be transmitted to a soil deposit

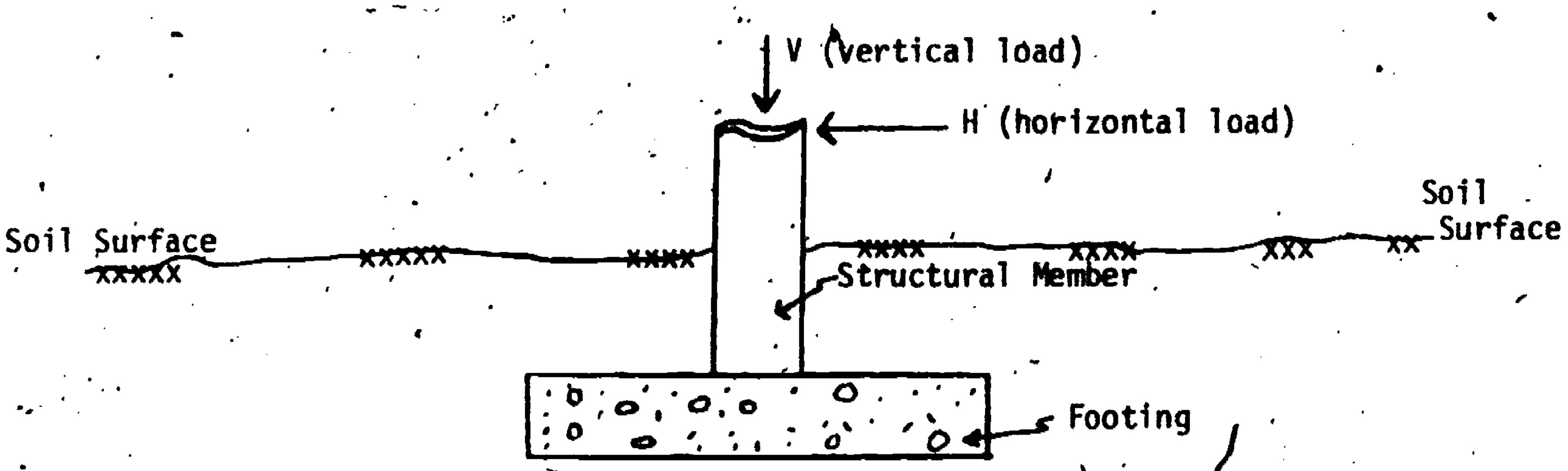
b. Examples:

i. Building column or beam
ii. Building wall
iii. Building mat
iv. Retaining wall footing
v. Offshore platform
vi. Bridge pier
vii. Highway abutment

3. Types of foundations

a. Spread footings

i. Sketch



ii. Shapes in plan view

- Square
- Rectangular
- Trapezoidal
- Combined

iii. Strap and cantilever footings

iv. Constructed of reinforced concrete generally, although plain concrete is occasionally used

v. Load is transmitted predominantly at the contact between the base of the footing and the soil deposit

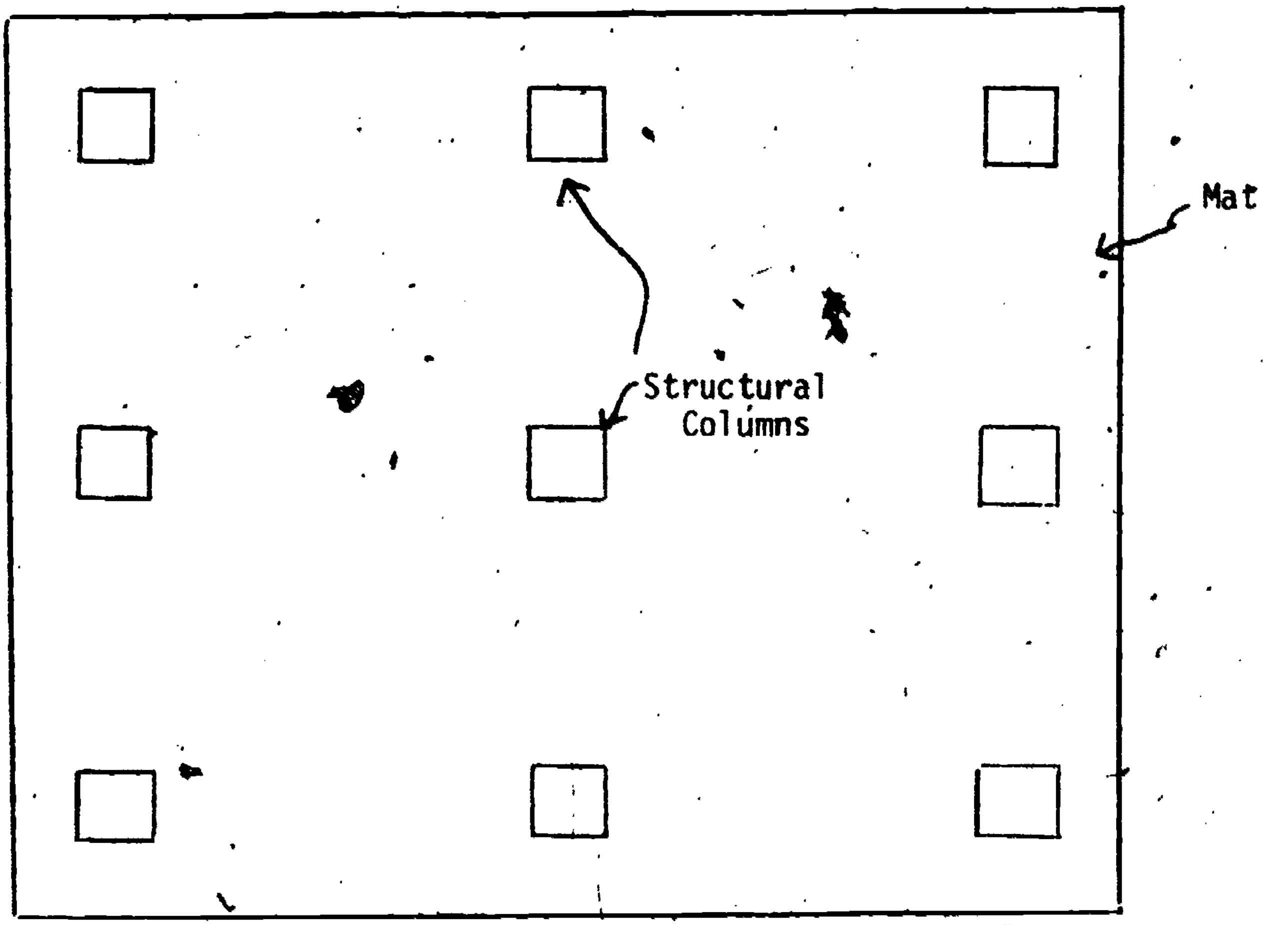
vi. Shallow foundation

b. Wall Footing

   i. Same as a rectangular spread footing except that H has considerable length

c. Mat foundation

   i. Sketch (Plan View)



Note: Sideview would show a relatively thick concrete mat placed at some depth below final grade and supporting the structural columns indicated

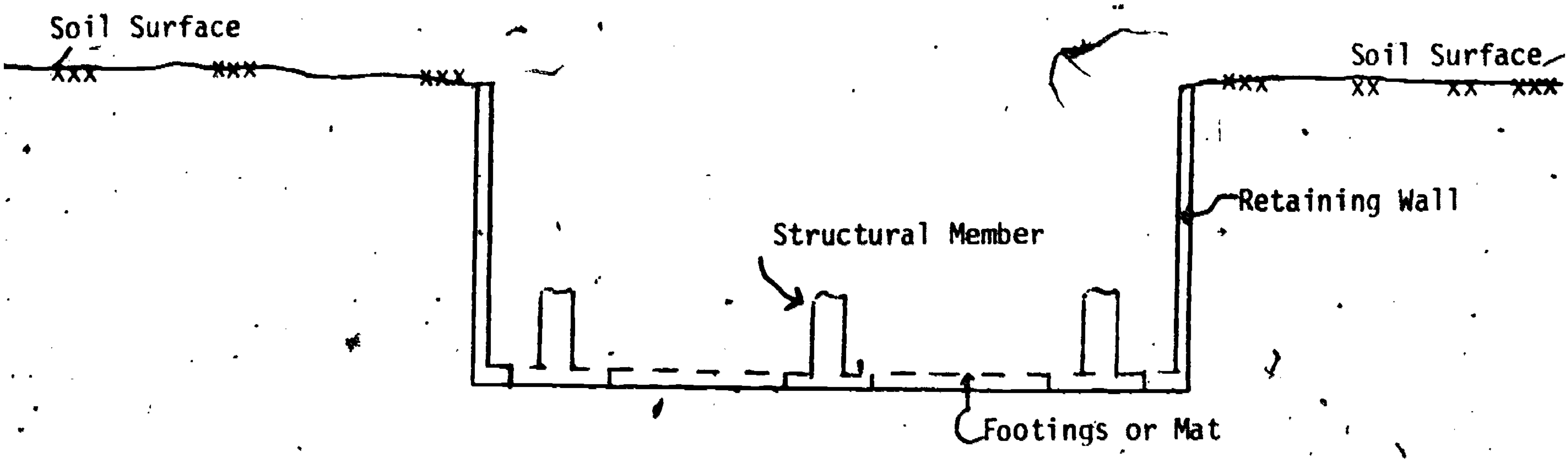
   ii. Constructed of reinforced concrete

   iii. Load is transmitted predominantly at the contact between the base of the mat and the soil deposit

   iv. Shallow foundation

d. Raft foundation

i. Sketch



ii. Loads are transmitted through footings or a mat placed at the base of an excavation

iii. Settlement reduced because of considerable removal of soil prior to foundation and structure construction

iv. Basement provided

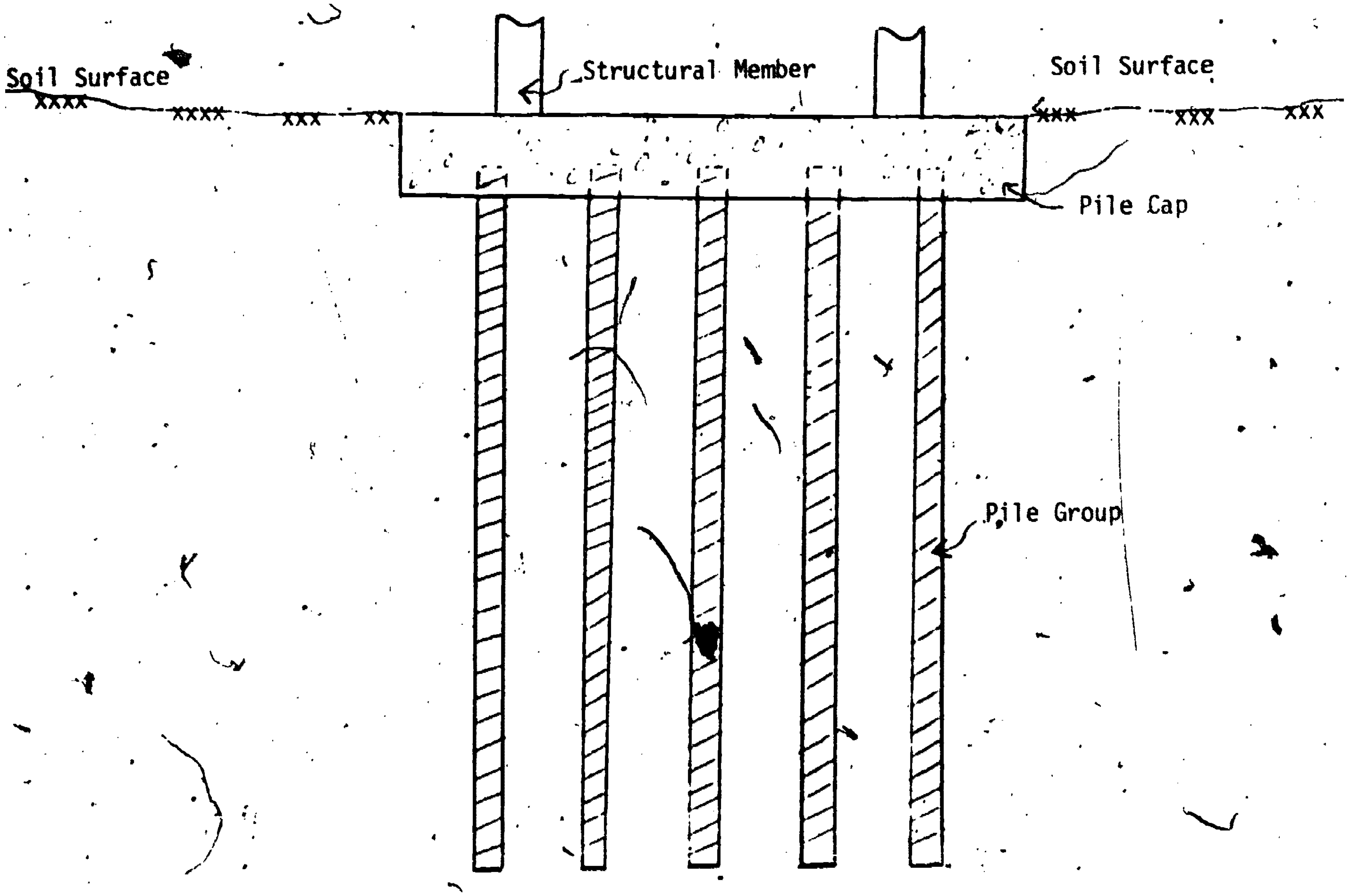
v. Generally constructed of reinforced concrete

vi. Load transmitted predominantly at the contact between the base of the foundations placed in the bottom of the excavation and the soil deposit. Some load can also be transmitted through the retaining wall.

vii. Foundation placed at moderate depth

e. Pile foundations

i. Sketch



ii. Number of piles per group, configuration of group, and spacing of piles variable

iii. Pile cap usually constructed of reinforced concrete

iv. Types of Piles

- Materials

  Timber
  Steel
  Reinforced or unreinforced concrete (may be prestressed)
  Composite piles

- Pile shapes

  Cylindrical
  Square or rectangular
  "H" or "I" section
  Continuous taper
  Step taper
  Sheets

- Methods of Installation

    Driven
    Predrilled hole
    Jetted

- Type of soil resistance generated

    Skin friction
    End bearing
    Combination of skin friction and end bearing

- Special Cases

    Franki piles

v. Pile Hammers

- Drop hammers
- Air driven hammers
- Steam driven hammers
- Diesel driven hammers
- Vibratory hammers

- Double acting versus single acting
- Pile driving stresses

vi. Pile driving formulas

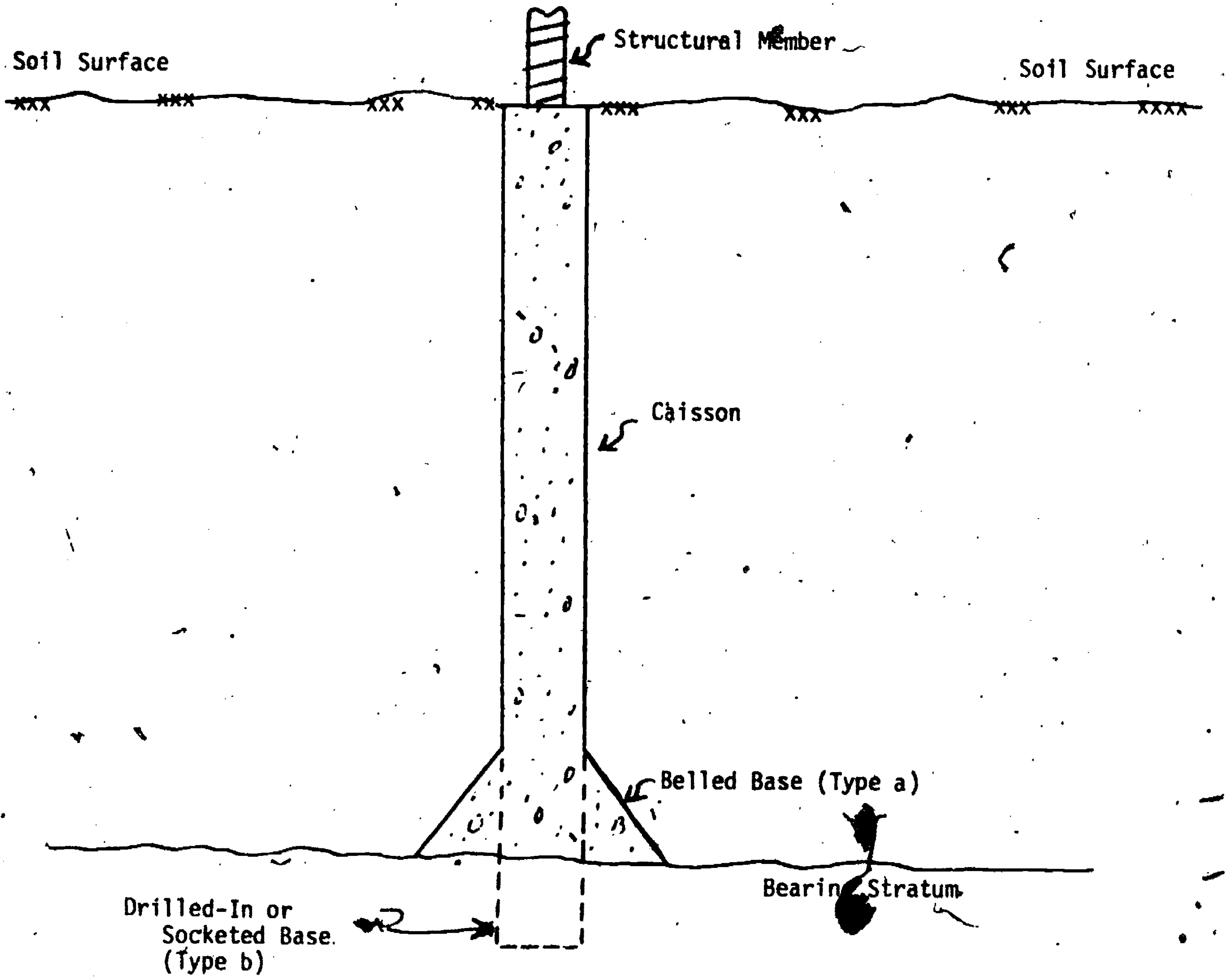
vii. Control of pile driving

viii. Pile load test

ix. Piles are used to transmit the desired load at depth in the soil deposit.

f. Caissons

i. Sketch (drilled caisson)



ii. Caisson constructed of reinforced or unreinforced concrete

iii. Load is transmitted to bearing stratum at depth

iv. Aspects of construction

- Drilling the hole
- Casing
- Belling (if required)
- Inspection
- Concrete and reinforcement (casing recovery if applicable)

v. Special Cases

- Open end caissons
- Closed end caissons
- Pneumatic caissons

4. General design procedures

   a. The particular design procedure to be followed will vary with the type of foundation to be utilized.

   b. General design procedure consists of:

      i. Sizing the foundation based on the applied loads to be transmitted to the soil deposit and:

         - Soil bearing capacity criterion
         - Soil settlement criterion
         - Construction feasibility

      ii. Determining the soil pressures which will act on the foundation

      iii. Calculating the forces, shear stresses and moments generated in the foundation structure by the "structural" loads and resulting soil pressure acting on it

      iv. Performing a structural design

         - Steel sections
         - Concrete sections and reinforcement
         - Timber sections
         - Connections

   c. Additional factors which must be considered in the design of foundations

      i. Economics
      ii. Location and characteristics of groundwater
      iii. Effects on surrounding structures
      iv. Construction procedures
      v. Building codes
      vi. Freezing and thawing
      vii. Site improvement (e.g. preloading)
      viii. Soil disturbance

   d. A completed design must be accompanied by construction drawings

5. Aspects of the construction of foundations

   a. Excavation and possible dewatering
   b. Concrete and reinforcement placement
   c. Construction work associated with retaining walls utilized if any (see prior discussion)
   d. Pile driving
   e. Pile splicing
   f. Pile and caisson drilling
   g. Pile jetting
   h. Fill construction
   i. Field load testing if requested

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411 Outline of Weekly Lecture Notes Prepared by: J. B. Thompson

Week No: 10 Date: 11/5/73

Lecture Subjects: Soil Slopes, Soil and Rockfill Dams, Subgrades, Course Review and Summary

Assignment: Read - pp. 255-293, 468-470, 479-490

Problems - To be assigned

Presentation

I. Design and Construction Problems Dealing with Soil (Emphasize Construction Problems)[continued]

A. Soil Slopes

1. Definition
   - a. A soil slope is any soil deposit having a sloping or non-horizontal surface.
   - b. Soil slopes can be composed of natural soils, man deposited soils, or a combination of the two

2. Utilization
   - a. Soil slopes are encountered in a wide variety of field problems
   - b. Examples:
     - i. highway cuts and fills
     - ii. railway cuts and fills
     - iii. earth dams and levees
     - iv. natural soil slopes treated by nature
     - v. land improvement or development
     - vi. retaining wall structures
     - vii. building excavations

3. Analyzing for the stability and safety of slopes
   - a. Most methods of analysis are based on equilibrium equations applied to an assumed failure mechanism
     - i. sliding wedge
     - ii. slip circles
   - b. Charts available
   - c. Building Codes

4. Techniques for increasing the stability of slopes
   a. Berms
   b. Decreasing the slope angle
   c. Decreasing the slope height
   d. Surcharging the base of the slope
   e. Removing loads existent atop the slope
   f. Draining the slope
   g. Placing a retaining structure
   h. Modifying the soil composing the slope
   i. Placing vegetation on the slope

5. Aspects of slope construction
   a. Excavation
   b. Fill placement
   c. Installation of drainage systems
   d. Construction of retaining structures
   e. Planting of vegetation

Notes: (1) It is important to realize that some slope failures are deep seated and are difficult to stabilize by using retaining structures.

(2) Nature's natural process is to flatten the land and all possible causes of slope failures should be realized before attempting a stabilization (e.g., Palos Verdes Hills)

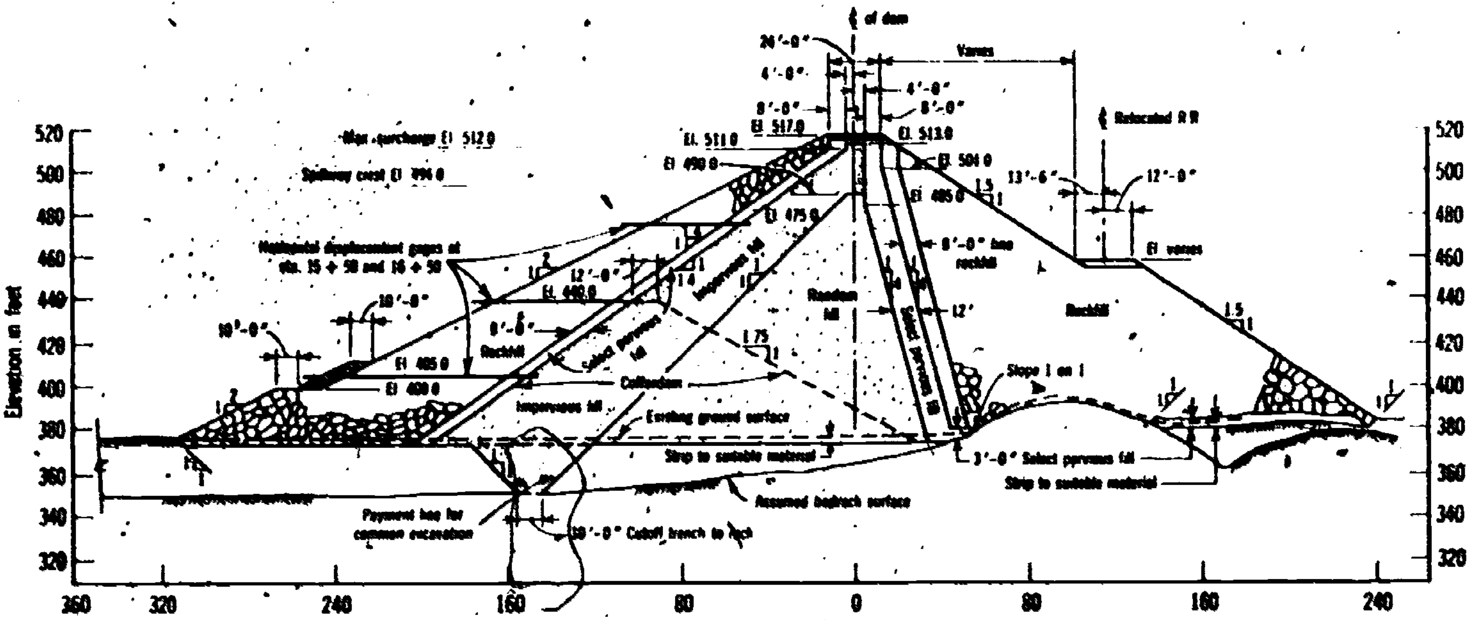
B. Soil and Rockfill Dams

1. Definition
   a. A soil or rock structure to safely retain a fluid which is frequently water
   b. A levee or some relatively small structure may be considered in general to act as a small dam

2. Utilization
   a. Reservoir installation
   b. Flood control
   c. Land reclamation
   d. Construction of projects adjacent to bodies of water
   e. Special purposes
      -tailings dams
      -mineral reclamation (evaporating basins)

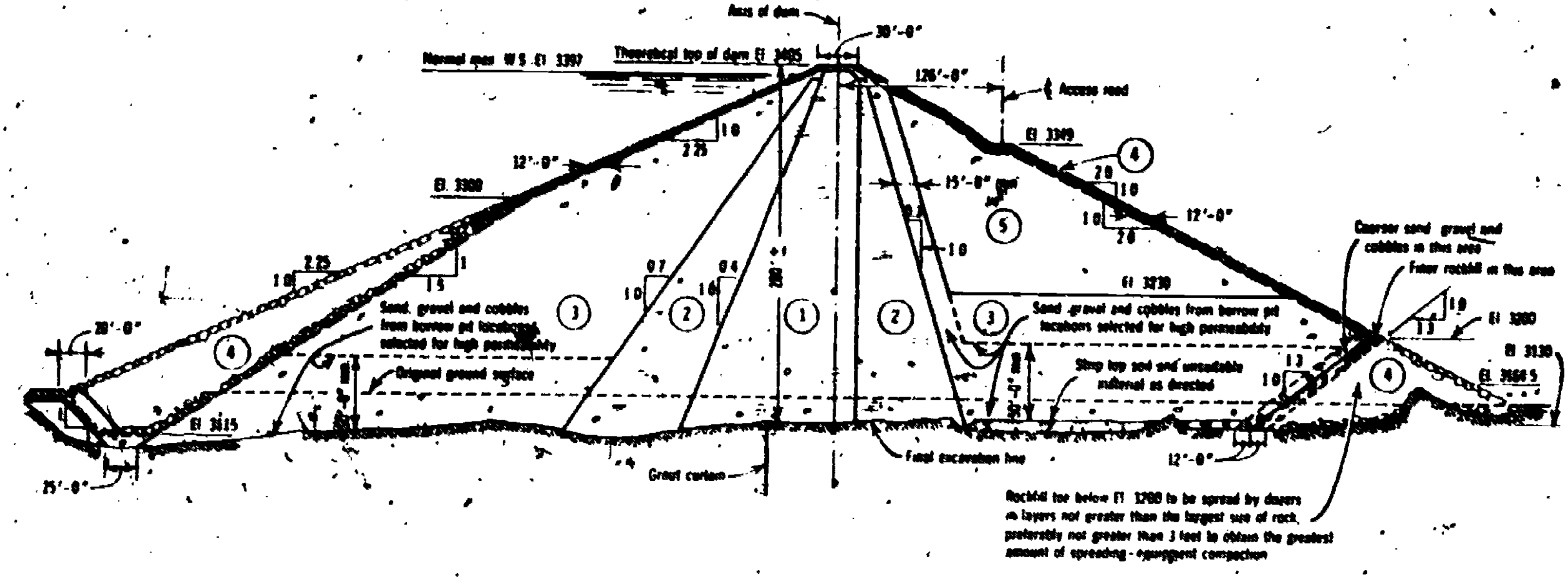
3. Typical soil and rockfill dam crossections
   a. Dam crossections utilized highly variable

b. Example 1



*Thomaston Dam, Connecticut.*

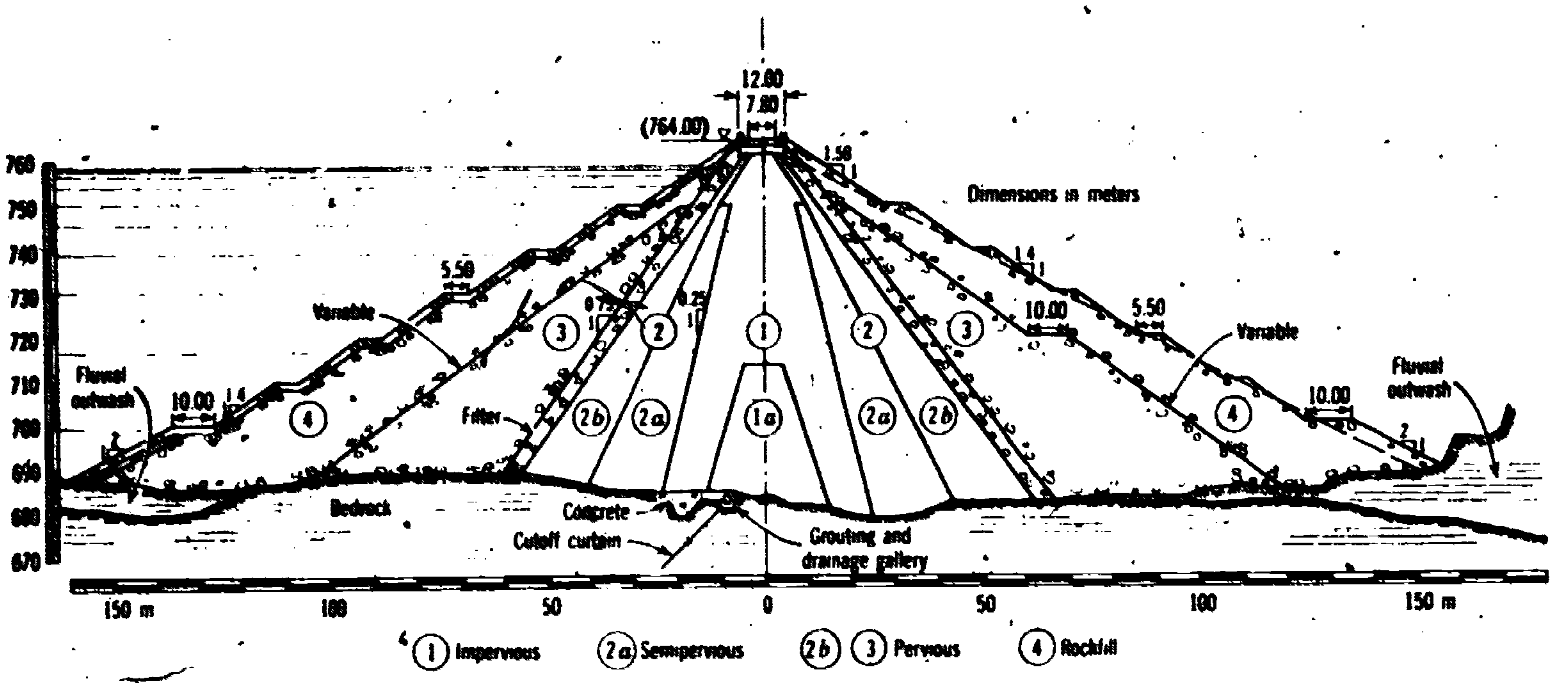
c. Example 2



① *Impervious rolled earth—to consist of a mixture of silt, fine to medium sand, and gravel not exceeding 3 in. max. dimension.*
② *Semipervious rolled earth, transition zone—to consist of fine to coarse sand and gravel not exceeding 3 in. max. dimension, together with some silt sizes. The finest material to be adjacent to zone ① with a gradual transition outwards.*
③ *Rolled sand, gravel, and cobbles—the finest material to be adjacent to zone ② and the coarsest adjacent to zone ④ and/or ⑤.*
④ *Dumped rockfill—to consist of rock fragments from required rock excavations and primarily composed of well graded fragments larger than ¼ ft.³ in volume with only enough rock spalls and gravel to fill voids in the coarser material.*
⑤ *Random fill—to have a min. dry weight = 115 lb./ft.³ and min. angle of internal friction = 35°*

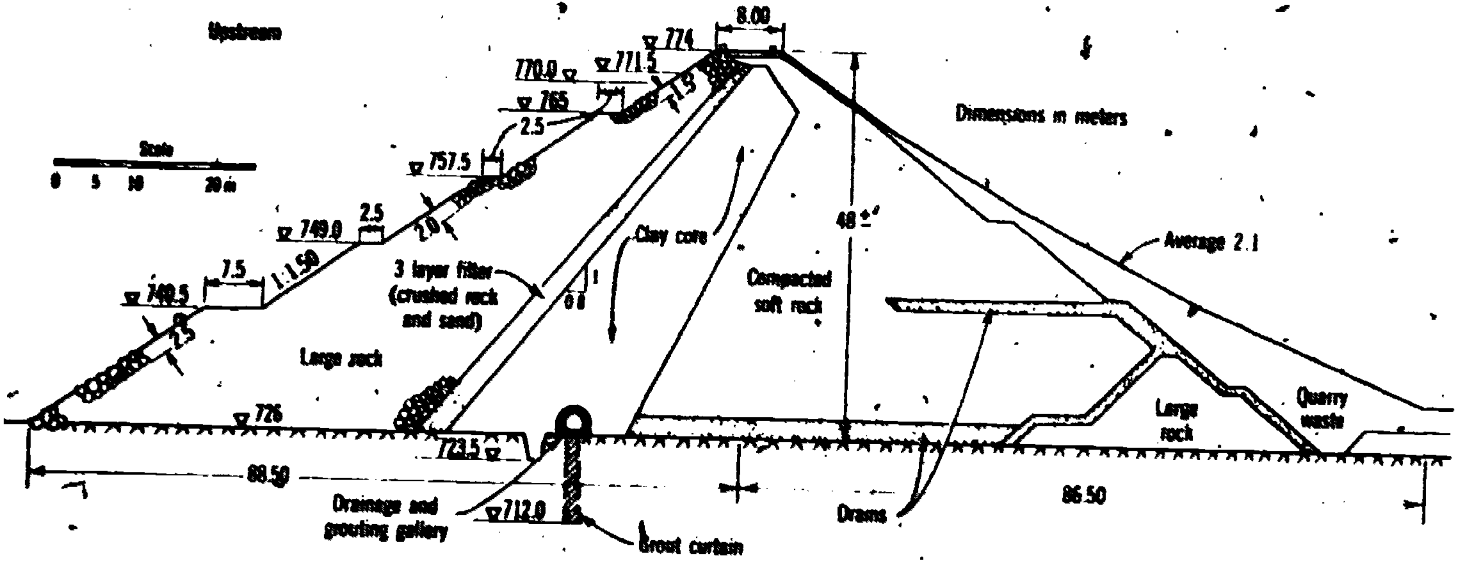
*Beardsley Dam, California.*

d. Example 3



*Las Pirquitas Dam, Argentina.*

e. Example 4



*Lokvarka Dam, Yugoslavia.*

4. Design considerations
    a. Source and transport of material
    b. Nature of the proposed site
    c. River diversion (if necessary)
    d. Probable wave action
    e. Construction feasibility
    f. Purpose of dam
    g. Seismicity of area
    h. Seepage
    i. Slope stability
    j. Settlement of foundation and structure
    k. Possible damage caused by burrowing of animals

5. Aspects of construction
    a. Supervision and inspection
    b. Excavation
    c. Fill construction
    d. Placement of slope protection (e.g., riprap, asphalt, soil cement, concrete)
    e. Climatic conditions
    f. Time schedules
    g. Foundation treatment (e.g., grouting, cutoffs, wells)

6. Construction instrumentation and cost construction inspections
    a. Piezometers
    b. Settlement and slope movement devices
    c. Stress devices
    d. Physical inspection (e.g., bowing, sand boils, cracks)
    e. Dam cores

Notes: (1) Dam design and construction is very much an art requiring considerable practical experience.

### C. Subgrades

1. Definition
    a. Soil subgrades are soil deposits designed and constructed primarily to support pavements

2. General design procedure for pavement thickness
    a. Determine the magnitude and frequency of the loads to be placed on the pavement
    b. Evaluate the characteristics of the subgrade at the site (existing or to be constructed)
    c. Establish the characteristics of the pavement and its base and subbase
    d. Select pavement, base, and subbase thickness
    e. Note that the characteristics of the subgrade influence the thickness of the components of the completed pavement
    f. Frost action is an important factor in pavement design
    g. Design charts

3. Evaluating the subgrade
    a. Stabilometer test
    b. Sand equivalent test

  - c. CBR test
  - d. Plate load test
  - e. Vibratory testing

4. Aspects of subgrade construction
   - a. Supervision and inspection
   - b. Excavation
   - c. Fill placement
   - d. Soil modification

D. Course Review

E. Course Summary

# CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

## CIVIL ENGINEERING DEPARTMENT

## ETC 411 - FOUNDATIONS AND SOIL MECHANICS

### Tentative Laboratory Schedule

Instructor: J. B. Thompson    Spring Quarter, 1975

Text: Lambe, T. William, Soil Testing for Engineers, John Wiley and Sons, Inc., New York, 1951.

| WEEK | DATE | TOPIC | ASSIGNMENT | |
|---|---|---|---|---|
| | | | READING | LABORATORY REPORTS |
| 1 | | Introduction<br>Atterberg Limits and Indices | 1-14, 22-28 | Report #1 |
| 2 | | Grain Size Analysis | 29-42 | Report #2 |
| 3 | | Permeability Test | 52-62 | Report #3 |
| 4 | | Compaction Test | 43-51 | Report #4 |
| 5 | | Field Density Tests | Handout | Report #5 |
| 6 | | Field Investigation | Handout | Report #6 |
| 7 | | Consolidation Test | 74-87 | Report #7 |
| 8 | | Direct Shear Test | 88-97, 138-146 | Report #8 |
| 9 | | Unconfined Compression Test | 110-121 | Report #9 |
| 10 | | Demonstration of Relative Density Test and Earthquake Simulation Testing, Summary | --- | --- |

Course Grading:

| | |
|---|---|
| Laboratory | 30% |
| Homework | 20% |
| Hour Exam | 20% |
| Final Exam | 30% |
| Total | 100% |

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411 Outline of Weekly Laboratory Notes Prepared by: J.B. Thompson

Week No: 1

Date: 11/5/73

Laboratory Topics: Introduction - Atterberg Limits and Indices

Assignment: Reading - 1-14, 22-28

Report Due - Laboratory Report #1

## Presentation

I. Check Roll

II. Discuss Course Laboratory Schedule

- A. Text
- B. Grade evaluation
  - 1: Course grading:
    Laboratory - 30%
    Homework - 20%
    Hour Exam - 20%
    Final Exam - 30%
    Total 100%
  - 2. Laboratory report policy:
    - a. Approximately one laboratory report per week
    - b. Each laboratory report normally due one week after laboratory exercise is conducted
    - c. Late reports will receive 1/2 credit
    - d. No laboratory reports will be accepted after returning the corrected reports
- C. Laboratory exercises to be conducted

II. Laboratory Orientation

- A. What is a soil?
  - 1. Illustrate
  - 2. Soil description and classification
- B. Why is soil tested?

C. Field testing

D. Laboratory testing

E. What tests are required in practical problems?

F. Why does this course have laboratory sessions?

G. What knowledge should be gained in these laboratory sessions?

IV. Organize Laboratory Groups

V. Atterberg Limits and Indices

A. Laboratory handout (see attached)

B. Soil to be tested

C. Test utilization

D. Basic principles

E. Laboratory procedures

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

ETC 411

## Lab No. 1 - Atterberg Limits and Indices

Purpose and Scope: The purpose of this laboratory is to examine the "Atterberg Limits" of soil and the techniques by which these characteristics can be determined.

There are three Atterberg Limits for a given soil: 1) Liquid Limit, 2) Plastic Limit, and 3) Shrinkage Limit. All three limits are rather arbitrary values derived from purely empirical testing procedures developed by Atterberg. In spite of this, the limits have found considerable acceptance and are quite useful in several soil engineering problems. From the determination of the liquid and plastic limit, another characteristic of a particular soil can be evaluated, the Plasticity Index. The Plasticity Index is defined mathematically as:

$$PI = LL - PL$$

where PI = Plasticity Index
LL = Liquid Limit
PL = Plastic Limit

A soil exhibiting a high PI has a large affinity for water (e.g., clay minerals). If the existing water content of the soil is known, its Liquidity Index (Lambe's Water Plasticity Ratio, B) is given by:

$$LI = \frac{w - PL}{PI}$$

where LI = Liquidity Index
w = existing water content

It is evident that an insitu soil having a low LI will behave as a soil with a water content on the low end of the range. This generally means that the soil will be stronger and less compressible. Two other indices of less practical significance that result from the Atterberg Limits and Indices Test are the Flow Index and the Toughness Index of the soil.

To reiterate, the results of the Atterberg Limits and Indices Test are only empirical and the procedures, I am sure, will seem arbitrary. Nevertheless, they are used today in lieu of more accurate, straight forward, and economical tests which may be developed in the future.

The primary use of the Atterberg Limits and Indices lies in the classification of soil. In particular, the Limits and Indices are used to classify fine grained soils such as silts, clays, and organic soils. The most popular classification system in use today is the Unified Soil Classification System. In this system, fine-grained soils are classified based on the

A-line plotted on a Plasticity Index (PI) versus Liquid Limit (LL) graph developed by Cassagrande. Basically, Cassagrande found that this was a convenient, consistent way of making these desired classifications. Many other uses have been found for the Atterberg Limits and Indices as applied to soil engineering design. It has been found that the compressibility of fine-grained, saturated soil deposits can be related to the LL of the deposit. "Off-the-road" trafficability in wet, fine-grained soils has been related to the deposit's Atterberg Limits and Indices. Finally, knowledge of the liquid limit, plastic limit, plasticity index, and liquidity index can provide considerable assistance to an experienced engineer in developing "a feel" for the possible behavior of a fine-grained soil deposit. For example, a soil with a liquidity index above 100 suggests the soil may be highly "sensitive." This means that if the soil is disturbed, it will suffer a loss in strength. Some clays such as Leda clay of Canada, Mexico City clay, etc., may lose as much as 75% of their strength on disturbance.

The soil sample to be analyzed will be specified later. It will be sieved on the No. 40 sieve before supplying it to you. The Shrinkage Limit test will not be performed.

B. Report Format - [Place report in a Cal Poly manila folder and complete cover entries.] (Minus 5 points if improperly done)

No. Points

(5) 1. Object: State in your own words the purpose of conducting this laboratory. Be specific about the methods used and the soil tested.

(5) 2. Procedure: Specify the procedure followed in conducting the laboratory test. Reference to your text or other standard procedures is permissible. Your reference must be complete and should state which of the optional procedures were followed if more than one procedure is included in the publication referenced. Also, state any deviations you made from the referenced procedure. Use standard referencing procedures.

(40) 3. Data and Results: Place in the format shown on page 28 of your text.

(5) 4. Sample Calculations: Perform and present a sample of each type of calculation performed.

(40) 5. Discussion and Questions: Respond to the following -

a. Classify your soil sample according to the Unified Soil Classification System. You may assume that more than half of the material is finer than the No. 200 sieve size. (Attach enough information to clearly indicate your steps.)

No. Points

5. (Continued)

b. Compare the values for the Limits and Indices determined by you to those reported by others. Reference your sources.

c. Could the Atterberg Limits and Indices be used to differentiate between a deposit of silt (containing no true clay minerals) and a deposit of clay minerals? How would you make this differentiation?

d. Could the Atterberg Limits and Indices be used to differentiate between a deposit composed of the clay mineral bentonite and a deposit composed of the clay mineral kaolinite? How would you make this differentiation?

e. From your experience in this laboratory, what effect does an increase in water content have on the behavior and characteristics of the soil sample tested?

f. What are the primary sources of error in this laboratory? Which of these errors did you commit and what effect might they have on the Limits and Indices determined from your tests?

(5) 6. Original Data Sheet

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411 Outline of Weekly Laboratory Notes Prepared by: J. B. Thompson

Week No: 2 Date: 11/5/73

Laboratory Topic: Grain Size Analysis

Assignment: Reading - 29-42

Report Due - Laboratory Report #2

## Presentation

I. Grain Size Analysis
   - A. Laboratory handout (see attached)
   - B. Soil to be tested
   - C. Test utilization
   - D. Basic principles
   - E. Laboratory procedures

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CIVIL ENGINEERING DEPARTMENT

ETC 411

## Lab No. 2 - Grain Size Analysis

Purpose and Scope: The purpose of this laboratory is to examine the "Grain Size Distribution" of soil and the techniques by which this characteristic can be determined.

The grain size distribution of a soil can be simply defined as the distribution by weight of the "particle sizes" found in that soil. The definition of "particle size" is somewhat arbitrary as most soil particles are irregular in shape. This definition is usually related to the test being used to determine the grain size distribution. In making a grain size analysis using sieves, the "particle size" can be thought of as being the minimum combination of particle crossectional dimensions that will allow passage of the particle through the square holes in the sieve. In making a grain size analysis using an Hydrometer, the "particle size" can be thought of as being the diameter of an equivalent spherical particle having the same particle density and the same free-fall velocity as the true soil particle. The results of a grain size analysis are usually presented in a plot of % finer by weight vs. $\log_{10}$(particle diameter in mm) as shown on page 42 of your laboratory text.

The primary reason for performing a grain size analysis on a soil is to enable its classification. Many classification systems are used due primarily to the fact that each system has been developed for application to particular soil engineering problems (e.g., BPR classification system). If the particular classification system you intend to use is based only on grain size distribution (e.g., MIT classification system), then a classification can be made after completing this grain size analysis. However, the classification system most commonly used by consulting soil engineers and others, the Unified Soil Classification System, requires additional tests to be conducted on the fine grained soils before classification can be made. These tests are the Atterberg Limits and Indices Tests performed last week. It should also be noted that there are a few design techniques in soil engineering using the results of a grain size analysis directly. Four examples are: 1) the determination of the permeability of soil to be used in seepage problems $[k = CD_{10}^2]$; 2) the design of filters to prevent erosion of soil by moving water; 3) the determination of the height to which water will rise in soil by capillary action; and 4) the determination of the frost susceptability of soil deposits.

The soil sample to be analyzed will be specified at a later date. A combined alternate analysis will be performed.

B. Report Format - [Place report in a Cal Poly manila folder and complete cover entries.] (Minus 5 points if improperly done.)

No. Points

(5) 1. Object: State in your own words the purpose of conducting this laboratory. Be specific about the methods used and the soil tested.

(5) 2. Procedure: Specify the procedure followed in conducting the laboratory test. Reference to your text or other standard procedures is permissible. Use standard referencing procedures. Your reference must be complete and should state which of the optional procedures were followed if more than one procedure is included in the publication referenced. Also, state any deviations you made from the referenced procedure.

(40) 3. Data and Results: Place in the format shown on pages 40, 41, and 42 of your text.

Note: A computer program is available for data reduction. If you desire to use it, please ask the instructor.

(5) 4. Sample Calculations: Perform and present a sample of each type of calculation performed.

(40) 5. Discussion and Questions: Respond to the following -

a. Classify your soil according to the MIT Classification System.

b. What is the average grain size of your soil?

c. What is the effective diameter of your soil?

d. What is the coefficient of uniformity of your soil?

e. Classify your soil according to the Unified Soil Classification System. Be as explicit as you can with the information available.

f. What are the primary sources of error in this laboratory? Which of these errors did you commit and what effect might they have on the distribution curve resulting from your analysis?

g. The Hydrometer analysis has a lower boundary on particle size below which the test is inaccurate. What is it? Why is this so?

(5) 6. Original Data Sheet.

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411

Week No: 3

Outline of Weekly Laboratory Notes

Prepared by:
J. B. Thompson

Date: 11/5/73

Laboratory Topic: Permeability Test

Assignment: Reading - 52-62

Report Due - Laboratory Report #3

## Presentation

Permeability Test

A. Laboratory handout (see attached)

B. Soil to be tested

C. Test utilization

D. Basic principles

E. Laboratory procedures

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

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ETC 411

## Lab No. 3 - Permeability Test

A. Purpose and Scope: The purpose of this laboratory is to examine the "permeability" of soil and the techniques by which this characteristic can be determined.

The permeability of soil is usually taken to mean the conductivity of the soil to the flow of pure water through it. The term could also be taken to mean the conductivity of the soil to the flow of other fluids such as air, methane, salt water, and oil through it. For each of these different fluids, the value of the soil "permeability" would be different.

Mathematically, the permeability of soil is defined in Darcy's Law:

$$v = ki \quad \text{or} \quad Q = kiA$$

where: $v$ = velocity of flow through soil (cm/sec.)
$Q$ = volumetric flow rate through soil ($cm^3$/sec.)
$k$ = soil permeability (cm/sec.)
$i = \Delta h/\Delta \ell$
$\Delta h$ = head loss in $\Delta \ell$ (same units as $\Delta \ell$)
$\Delta \ell$ = differential length (same units as $\Delta h$)
$A$ = cross sectional area normal to direction of flow ($cm^2$)

These equations state that a driving force, the hydraulic gradient (i), causes fluid to flow through the soil at some rate (v or Q) in proportion to the soil permeability (k). In other words the same driving force will produce different flow rates in different soils and the flow rate produced will depend on the permeability of the soil.

The permeability of a given soil will depend on many factors including the nature of the fluid flowing through it, the size of the soil grains, the void ratio of the soil, the degree of saturation, etc. The influence of these factors is discussed in detail in your laboratory text. I do wish to point out though that soil permeability is highly variable. For example, the permeability of gravel can approach 1 cm/sec., whereas the permeability of clay can be as low as $10^{-8}$ cm/sec. Generally the permeability of gravel > sand > silt > clay > rock.

Soil permeability finds many uses in practical soils engineering. In the field of soil mechanics and foundation engineering, the permeability of the soil is directly or indirectly involved in almost all designs if water is present near the surface of the natural deposit. Obvious applications involve the design of earth and rock fill dams, the stability of slopes, design of retaining walls, etc. Soil permeability is also used in the fields of highway design (drainage problems), and water supply (well problems).

The soil sample to be analyzed is a graded Ottawa sand with the ASTM Designation C-109. This sand was obtained from Ottawa, Illinois and it has been processed The sand has rounded particles. Constant head and falling head permeability tests will be performed.

Report Format - [Place report in a Cal Poly manila folder and complete cover entries.] (Minus 5 points if improperly done).

<u>No. Points</u>

5 1. Object: State in your own words the purpose of conducting this laboratory. Be specific about the methods used and the soil tested.

5 2. Procedure: Specify the procedure followed in conducting the laboratory test. Reference to your text or other standard procedures is permissible. Use standard referencing procedures. Your reference must be complete and should state which of the optional procedures were followed if more than one procedure is included in the publication referenced. Also, state any deviations you made from the referenced procedure.

40 3. Data and Results: Place in format shown on data sheets provided.

5 4. Sample Calculations: Perform and present a sample of each type of calculation performed.

40 5. Discussion and Questions: Respond to the following -

- a. Compare your measured permeabilities to values reported by others. Properly reference the other values you are using for comparison.
- b. What functional relationship between permeability and void ratio best describes the soil you tested?
- c. What are the primary sources of error in this laboratory? Which of these errors did you commit and what effect might they have on the permeability values determined?
- d. Could the set up and test procedures used be applied to the determination of the permeability of clay? What difficulties might be encountered?
- e: What effect would doubling the head loss have had on the volumetric rate of flows (Q's) measured in your experiments? On the flow velocities, v's?
- f. What effect would a change in ambient temperature to 30°C have had on the volumetric rate of flows, (Q's) measured in your experiments? On the flow velocities, v's?
- g. What effect would doubling the permeater diameter have had on the volumetric rate of flows (Q's) measured in your experiments? On the flow velocities, v's?

5 6. Original Data Sheets

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CIVIL ENGINEERING DEPARTMENT

Course: ETC 411 **Outline of Weekly Laboratory Notes** Prepared by: J. B. Thompson

Week No. 4

Date: 11/5/73

Laboratory Topic: Compaction Test

Assignment: Reading - 43-51

Report Due - Laboratory Report #4

## Presentation

I. Compaction Test
  A. Laboratory handout (see attached)
  B. Soil to be tested
  C. Test utilization
  D. Basic principles
  E. Laboratory procedures

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## Lab No. 4 - Compaction Test

A. Purpose and Scope: The purpose of this laboratory is to examine the response of soil to a "compactive effort" and the techniques by which this response can be determined.

The compaction of a soil is defined as the densification of the soil by decreasing the volume of air within that soil. On the other hand, consolidation of a soil is defined as the densification of the soil by decreasing the volume of water within that soil. Compaction of soil, therefore, does not change the volume of water within the soil.

Compaction of soil usually results in an increase in soil stiffness and strength. This increase in soil stiffness and strength is of course due to the densification of the soil. It is known that for a given compaction energy per unit volume of soil that the amount of soil densification will depend primarily on the water content at which the soil is compacted. Because of this, the standard technique used for presenting the results of a compaction test is a plot of the dry unit weight of the soil ($\gamma_d$) versus compaction water content at a given compaction energy per unit volume. The dry unit weight of course indicates the density of the soil solids matrix.

The primary use of the compaction test lies in the construction of engineered fills. These fills are frequently placed in the construction of developments, highways, buildings, dams, and in construction on any site at which the natural soil deposit is too compressible or weak to support the design loads and this method of soil improvement is chosen as the solution to the problem. Specifically, the compaction test is performed to provide: 1) a basis for the control of the construction of engineered fills, and 2) laboratory specimens of the fill to be constructed on which other laboratory testing can be performed. Frequently, the critical specification a contractor must meet in the construction of an engineered fill is that his fill must have a specified dry unit weight at a specified moisture content. The specified dry unit weight and the correspondong water content are determined from the laboratory compaction test using the same compaction energy per unit volume as the contractor is likely to use, and additional laboratory tests run on this compacted soil. These additional tests might include: 1) Specific Gravity Test, 2) Grain Size Analysis, 3) Atterberg Limits and Indices Test, 4) Permeability Test, 5) Direct Shear Test, 6) Triaxial Compression Test, 7) CBR Test, 8) Stabilometer Test (R value) and/or 9) Swell Test.

The soil to be tested in this laboratory will be the same one that was tested in the "Grain Size Analysis" laboratory. A Standard Proctor test will be performed.

Other standard compaction tests will be demonstrated.

B. Report Format - [Place report in a Cal Poly manila folder and complete cover entries.] (Minus 5 points if improperly done.)

No. Points

(5) 1. Object: State in your own words the purpose of conducting this laboratory. Be specific about the methods used and the soil tested.

(5) 2. Procedure: Specify the procedure followed in conducting the laboratory test. Reference to your text or other standard procedures is permissible. Use standard referencing procedures. Your references must be complete and should state which of the optional procedures were followed if more than one procedure is included in the publication referenced. Also, state any deviations you made from the referenced procedure.

(40) 3. Data and Results: Place in the format shown on pages 50 and 51 of your text.

(5) 4. Sample Calculations: Perform and present a sample of each type of calculation performed.

(40) 5. Discussion and Questions: Respond to the following -

a. What are the optimum water content and maximum dry density from your test?

b. What are the primary sources of error in this laboratory. Which of these errors did you commit and what effect might they have on the dry density versus water content plot resulting from your tests?

c. Qualitatively, what effect would the use of a heavier hammer have on the location of the dry density versus water content plot? A lighter hammer?

d. Qualitatively, what effect would the use of thinner lift heights have on the location of the dry density versus water content plot? Thicker lift heights?

e. Qualitatively, what effect would the use of fewer blows/lift have on the location of the dry density versus water content plot? More blows/lift?

f. Qualitatively, what shape might you expect for a dry density versus water content plot resulting from a compaction test run on clean gravel.

g. What is the most efficient way of compacting clay, sand? [Choose between static and vibratory methods].

(5) 6. Original Data Sheet

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Course: ETC 411 Outline of Weekly Laboratory Notes Prepared by: J.B. Thompson

Week No: 5

Date: 11/5/73

Laboratory Topic: Field Density Tests

Assignment: Reading - Handout

Report Due - Laboratory Report #5

Presentation

I. Field Density Tests

A. Laboratory handout (see attached)

B. Soil deposit to be tested

C. Utilization of tests

D. Basic principles

E. Field procedures

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## Lab No. 5 - Field Density Tests

A. Purpose and Scope: The purpose of this laboratory is to examine the techniques by which the field density of surficial soil deposits such as engineered fills may be determined.

The field density of engineered fills must be determined in order to decide if the fill is being compacted according to the specifications. The desired field density is determined by performing laboratory compaction tests on the soil to be used as the fill. A typical laboratory compaction test, the Standard Proctor Compaction Test, was performed by you last week. From such a test, an optimum water content and a corresponding maximum dry density can be obtained. The desired field density is usually expressed as some percent of this maximum dry density.

To decide if this desired field density is being obtained during the construction of the fill, field density tests are conducted. Several such tests are: (1) Sand Cone Method, (2) Rubber Balloon Method, (3) Block Samples, and (4) Nuclear Density Moisture Meter Method. The first three methods generally involve: (1) removing a volume of soil of known weight from the fill in the field, (2) determining the water content of the soil removed, (3) measuring the volume of the soil removed (it is in this step that the differences in the three testing techniques occur), (4) computing the field dry density $\left(\gamma_d = \frac{W/V}{1+w}\right)$. The last test technique mentioned above, the Nuclear Density Moisture Meter Method, is based on a different principle which has to do with the back scattering of nuclear particles transmitted by the device.

Field density tests will be performed in this laboratory using the Sand Cone Method, the Rubber Balloon Method, and the Nuclear Moisture Density Meter Method.

B. Report Format - [Place report in a Cal Poly manila folder and complete cover entries.] (Minus 5 points if improperly done).

No. Points

(5) 1. Object: State in your own words the purpose of conducting this laboratory. Be specific about the methods used and the soil deposit tested.

(5) 2. Procedure: Specify the procedure followed in conducting the laboratory test. Reference to your text or other standard procedures is permissible. Your reference must be complete and should state which of the optional procedures were followed if more than one procedure is included in the publication referenced. Also, state any deviations you made from

the referenced procedure. Use standard referencing procedures.

(40) 3. Data and Results: Place in the format shown on the data sheets provided.

(5) 4. Sample Calculations: Perform and present a sample of each type of calculation performed.

(40) 5. Discussion and Questions: Respond to the following -

a. What are the primary sources of error in this laboratory? Which of these errors did you commit, and what effect might they have on your results?

b. Compare the results obtained by the three different methods used.

c. Compare the accuracy of the three different methods used.

d. If the required maximum dry density of the fill tested was 100 pcf, was the fill specification met during construction?

(5) 6. Original Data Sheets

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411

Week No: 6

## Outline of Weekly Laboratory Notes

Prepared by:
J. B. Thompson

Date: 11/5/73

Laboratory Topic: Field Investigation

Assignment: Reading - Handout

Report Due - Laboratory Report #6

## Presentation

I. Field Investigation:
  A. Laboratory handout (see attached)
  B. Site of investigation
  C. Purposes of field investigations
  D. Basic techniques for performing field investigations
  E. Laboratory procedure

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## Lab No. 6 - Field Investigation

A. Purpose and Scope: The purpose of this laboratory is to gain experience with the techniques and procedures used in conducting a field investigation of a deposit of soil. In addition, soil specimens will be obtained for testing in later laboratory sessions.

A variety of information is usually obtained in a general field investigation ranging from observations on the overall topographic conditions at the site to securing specific samples of the soil existing at the site. General descriptions of the site are a useful tool in interpreting the results of laboratory tests conducted on the soil samples and in anticipating possible problems which may exist at the site and are indicated by their surface features (e.g., sink holes, weep holes, high water marks, etc.). The primary function of most field investigations, however, is to obtain samples of the soil at the site to be tested in the laboratory. These laboratory tests are conducted to classify the soil and to obtain the necessary design values. Soil deposits are also tested in situ (e.g., standard penetration test, plate load test, permeability test, etc.) when the conditions of the deposit or the nature of the job require such tests.

One boring will be made in this class. Both split spoon and Shelby tube (thin wall) soil samples will be taken. The elevation of the water table will also be recorded.

B. Report Format - [Place report in a Cal Poly manila folder and complete cover entries.] (Minus 5 points if improperly done.)

No. Points

(5) 1. Boring Location - Show the location of the boring on the maps supplied.

(30) 2. Boring Log - Compile a boring log for the boring performed. Include:

a. A heading (include the technique used to make the boring and the location of the boring).

b. Ground surface elevation at the boring

c. Depth to the boundaries between the soil layers

d. Field classification of each soil layer

e. Depth at which soil samples were taken and method used

f. Standard penetration test results (elevation taken and values)

g. Depth at which moist soil was first encountered

h. Depth to the ground water table

i. Depth and elevation at the bottom of the boring

(10) 3. State any general observations concerning the area in which the boring was made which might be of importance to a civil project.

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CIVIL ENGINEERING DEPARTMENT

Course: ETC 411 / Outline of Weekly Laboratory Notes

Week No: 7

Prepared by: J. B. Thompson

Date: 11/5/73

Laboratory Topic: Consolidation Test

Assignment: Reading - 74-87

Report Due - Laboratory Report #7

## Presentation

I. Consolidation Test

- A. Laboratory handout (see attached)
- B. Soil to be tested
- C. Test utilization
- D. Basic principles
- E. Laboratory procedures

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## Lab No. 7 - Consolidation Test

A. Purpose and Scope: The purpose of this laboratory is to examine "soil consolidation" and the techniques by which this response of wet soil to loading may be determined.

Soil consolidation is a response of soil to loading and refers to the densification of wet soil by the applied load. This densification is due entirely to the expulsion of pore water from the soil by the applied load. Soil compaction, on the other hand, refers to soil densification due to the expulsion of pore air.

As a result of the expulsion of pore water, the void ratio of the soil is decreased and the dimensions (thickness, height, width, etc.) are decreased. Consolidation results in a decrease in the volume of the overall soil body. This expulsion of water from the soil voids can t[illegible] considerable amount of time, particularly in low permeability [illegible] Consolidation problems, therefore, involve calculations pertaining [illegible] the total amount of consolidation which will ever occur and to the amount which will occur in a specified time.

The consolidation test to be performed in this laboratory is one of the simpler varieties. In this test, lateral displacement of the soil is prevented and incremental loads are applied vertically. The displacement of the soil surface is measured as a function of time to determine the rate at which consolidation is occurring and the total amount of consolidation which occurs ultimately. Other types of special consolidation tests involving different soil boundary conditions and different sequences of applied loads are also used. However, tests of the type to be performed in this laboratory are most frequently encountered.

The primary practical application of the consolidation test lies in settlement calculations for structures placed on wet soil. The settlement of a structure is, of course, an important design criterion. Certain intermediate steps are required before the final settlement calculations can be performed but it is essentially assumed that a structure placed on wet soil settles as a result of the consolidation (densification by expulsion of pore water) of that soil. This assumption proves to be quite accurate.

The soil to be tested in this laboratory will be the soil obtained during Lab 6 - "Field Investigation."

B. Report Format - [Place report in a Cal Poly manila folder and complete cover entries.] (Minus 5 points if improperly done.)

| No. Points | |
|---|---|
| (5) | 1. Object: State in your own words the purpose of conducting this laboratory. Be specific about the methods used and the soil tested. |
| (5) | 2. Procedure: Specify the procedure followed in conducting the laboratory test. Reference to your text or other standard procedures is permissible. Use standard referencing procedures. Your references must be complete and should state which of the optional procedures were followed if more than one procedure is included in the publication referenced. Also, state any deviations you made from the referenced procedure. |
| (40) | 3. Data and Results: Place in the format shown on pages 85, 86, and 87 of your text. |
| (5) | 4. Sample Calculations: Perform and present a sample of each type of calculation performed. |
| (40) | 5. Discussion and Questions: Respond to the following - |

a. Calculate the Compression Index, $C_c$, of your soil. Compare your value to those reported by others. Properly reference.

b. Compare your values for the Coefficient of Consolidation, $c_v$, of your soil to those reported by others. Properly reference.

c. Determine the preconsolidation pressure for your soil. Make an estimate as to whether this soil is underconsolidated, normally consolidated, or overconsolidated.

d. What are the primary sources of error in this laboratory? Which of these errors did you commit and what effect might they have on your results?

e. Why is a specimen diameter to thickness ratio of about three to four used in the consolidation test?

No. Points

5. Discussion and Questions: (continued)

   f. What would be the relative times to reach 100% consolidation for a sand specimen and a clay specimen having the same dimensions under the same increment of load? Why?

   g. Did you perform a "fixed-ring" or "floating-ring" test? What are advantages and disadvantages of the test type you performed?

   h. Specify a practical field problem exactly simulated by the consolidation test performed in this laboratory.

(5) 6. Original Data Sheet

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CIVIL ENGINEERING DEPARTMENT

Course: ETC 411 Outline of Weekly Laboratory Notes Prepared by: J. B. Thompson

Week No: 8

Date: 11/5/73

Laboratory Topic: Direct Shear Test

Assignment: Reading - 88-97, 138-146

Report Due - Laboratory Report #8

Presentation

I. Direct Shear Test

  A. Laboratory handout (see attached)

  B. Soil to be tested

  C. Test utilization

  D. Basic principles

  E. Laboratory procedures

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## Lab No. 8 - Direct Shear Test

A. Purpose and Scope: The purpose of this laboratory is to investigate the strength and stress-strain characteristics of soil and the Direct Shear Test technique by thich these characteristics may be determined. This laboratory will be limited to testing cohesionless soil.

The strength of soil has been found to be a function of the soil cohesion, c, the soil angle of internal friction, $\phi$, and the magnitude of the normal stress acting on the failure plane, $\sigma_n$. Mathematically, soil strength is defined by the Mohr-Coulomb failure criterion:

$$\tau = c + \sigma_n \tan \phi = \text{shear stress on the failure plane}$$

For cohesionless soil, the cohesion, c, is generally taken to be equal to zero which is accurate as long as the $\sigma_n \tan \phi$ term is significant. The equation reduces to:

$$\tau = \sigma_n \tan \phi$$

Ideally, $\sigma_n$ should be taken as an effective stress and $\phi$ would then be the effective stress angle of internal friction ($\phi'$). Normally, however, such care is not taken and $\sigma_n$ is taken as a total stress and $\phi$ as the total stress angle of internal friction. As a result, difficulties in duplicating field conditions ~~can lead~~ to inaccurate values of $\phi$ for use in design.

The stress-strain characteristics desired for soil are the same as those desired for other materials. A crucial characteristic to notice is whether the soil is compressed or whether the soil dilates during shear. This information is used to provide general information about the expected behavior of the soil.

Soil strength and stress-strain information is needed in any practical problem involving the loading of soils. Some examples include foundation design, highway subgrades, stability of natural and man-made slopes, and others. In particular, the strength characteristics are used in failure analyses and the stress-strain characteristics are used in solving deformation problems.

The graded Ottawa sand will be tested in this laboratory.

B. Report Format - [Place report in a Cal Poly manila folder and complete cover entries.] (Minus 5 points if improperly done.)

No. Points

(5) 1. Object: State in your own words the purpose of conducting this laboratory. Be specific about the methods used and the soil tested.

(5) 2. Procedure: Specify the procedure followed in conducting the laboratory test. Reference to your text or other standard proceedures is permissible. Your references must be complete and should state which of the optional procedures were followed if more than one procedure is included in the publication referenced. Also, state any deviations you made from the referenced procedure. Use standard referencing procedures.

(40) 3. Data and Results: For each test performed, place data and results in the format shown on pages 96 and 97 of your text. Summarize the results of your laboratory section by plotting a figure similar to Figure X - II of your text and by listing the peak and ultimate values as shown on page 95.

(5) 4. Sample Calculations: Perform and present a sample of each type of calculation performed.

(40) 5. Discussion and Questions: Respond to the following -

a. Compare your values of peak friction angle, $\phi_m$, and ultimate friction angle, $\phi_u$, to those reported by others. Properly reference.

b. What are the primary sources of error in this laboratory? Which of these errors did you commit and what effect might they have on your results.

c. The Ottawa sand is a rounded sand. What changes in the friction angles would result if a more angular sand were tested.

d. The Ottawa sand is a poorly graded (uniform) sand. What changes in the friction angles would result if a more well graded sand were tested.

e. Your lab group conducted tests at the same applied normal stress. What effect would a higher normal stress have had on the values of the friction angles determined? A lower normal stress?

No. Points

f. What effect would changes in strain rates at which the specimens are tested have on the stress-strain curves and friction angles measured.

(5) 6. Original Data Sheet

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411 Outline of Weekly Laboratory Notes

Week No: 9

Prepared by:
J. B. Thompson

Date: 11/5/73

Laboratory Topic: Unconfined Compression Test

Assignment: Reading - 110-121

Report Due - Laboratory Report #9

**Presentation**

I. Unconfined Compression Test

  A. Laboratory handout (see attached)

  B. Soil to be tested

  C. Test utilization

  D. Basic principles

  E. Laboratory procedures

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

ETC 411

## Lab No. 9 - Unconfined Compression Test

A. Purpose and Scope: The purpose of this laboratory is to investigate the strength and stress-strain characteristics of soil using the "Unconfined Compression Test" technique.

The Unconfined Compression Test is normally restricted to testing saturated fine grained materials (e.g., clay). Theoretically, it can be shown that the results from this one test will be the same as those from a series of Unconsolidated-Undrained triaxial compression tests. Therefore, the test may be considered to be an efficient method of evaluating soil strength and stress-strain properties. It should be noted that the sample <u>must</u> be saturated for the above statement to be valid.

If we are considering a saturated soil, it is known that the undrained angle of internal friction of this soil will be zero [this test is an undrained test]. As a result, the strength of the soil is defined as:

$$\tau = c + \sigma_n \overset{0}{\cancel{\tan \emptyset}} = c$$

This test is used to determine the soil cohesion, c.

Stress-strain information generated from this test are used to solve various soil mechanics and foundation engineering deflection problems.

The soil to be tested in this laboratory is the soil obtained from Lab 6 - "Field Investigation." Tests will be performed only on undisturbed specimens.

B. Report Format - [Place report in a Cal Poly manila folder and complete cover entries.] (Minus 5 points if improperly done.)

<u>No. Points</u>

(5) 1. Object: State in your own words the purpose of conducting this laboratory. Be specific about the methods used and the soil tested.

(5) 2. Procedure: Specify the procedure followed in conducting the laboratory test. Reference to your text or other standard procedures is permissible. Your references must be complete and should state which of the optional procedures were followed if more than one procedure is included in the publication referenced. Also, state any deviations you made from the referenced procedure. Use standard referencing procedures.

No. Points

(40) 3. Data and Results: Place in the format shown on pages 120 and 121 of your text.

(5) 4. Sample Calculations: Perform and present a sample of each type of calculation performed.

(40) 5. Discussion and Questions: Respond to the following -

a. Compute the cohesion of your soil.

b. Compare your value for cohesion to those reported by others. Properly reference.

c. Draw the Mohr's Circle for the failure stresses applied to your specimen.

d. Classify your clay according to its consistency.

e. What effect would a higher rate of strain have had on the cohesion determined for your specimen?

f.* Derive the equation for the revised or instantaneous specimen cross-sectional area used in your data reduction.

g. What effect would specimen remolding likely have on the strength and stiffness of your specimen?

(5) 6. Original Data Sheet

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

CIVIL ENGINEERING DEPARTMENT

Course: ETC 411 **Outline of Weekly Laboratory Notes** Prepared by: J. B. Thompson

Week No: 10

Date: 11/5/73

Laboratory Topics: Relative Density Test, Earthquake Simulation Testing, Summary

Assignment: Reading -

Report Due:

**Presentation**

I. Relative Density Test Demonstration
   - A. Test utilization
   - B. Basic principles
   - C. Laboratory procedures
   - D. Demonstration

II. Earthquake Simulation Testing Demonstration
   - A. Test utilization
   - B. Basic principles
   - C. Laboratory procedures
   - D. Demonstration

III. Summary of Laboratory Sessions

## Appendix

## SUMMARY OF ITEMS PURCHASED UNDER NSF GRANT GY-10474

| Laboratory Exercise | Item(s) | Quantity | Expenditure | |
|---|---|---|---|---|
| Grain Size Analysis Test | 1. 8" Diameter Sieves | | | |
| | 1/2" sieve | 1 | $ 14.95 | |
| | No. 4 sieve | 1 | 14.95 | |
| | No. 8 sieve | 1 | 13.75 | |
| | No. 16 sieve | 1 | 13.75 | |
| | No. 30 sieve | 1 | 13.75 | |
| | No. 60 sieve | 1 | 13.75 | |
| | No. 100 sieve | 1 | 14.25 | |
| | No. 140 sieve | 1 | 15.80 | |
| | No. 200 sieve | 1 | 19.50 | |
| | Pan | 1 | 7.50 | |
| | Cover | 1 | 4.70 | |
| | 2. Gilson Screen Trays | | | |
| | No. 4 | 1 | 28.00 | |
| | No. 8 | 1 | 36.00 | |
| | No. 16 | 1 | 40.00 | |
| | No. 30 | 1 | 40.00 | |
| | No. 60 | 1 | 40.00 | |
| | No. 100 | 1 | 40.00 | |
| | No. 200 | 1 | 64.00 | |
| | 3. Sieving Timers | 2 | 58.00 | |
| | | | | $492.65 Subtotal |
| Consolidation Test | 1. Specimen Cutter | 4 | 38.00 | |
| | | | | 38.00 Subtotal |

| Laboratory Exercise | Item(s) | Quantity | Expenditure |
|---|---|---|---|
| Direct Shear Test | 1. Motorize Direct Shear Test | 1 | $ 695.00 |
| | 2. Shear Box Coupling | 1 | 13.50 |
| | 3. Spare Gripper Assembly | 1 | 43.50 |
| | | | $ 752.00 Subtotal |
| Relative Density Test | 1. Relative Density Test Equipment | 1 | $1,277.60 |
| | | | $1,277.60 Subtotal |
| Permeability Test | 1. Plastic | Two experimental set-ups designed & fabricated | $ 162.00 |
| | 2. Wood and Bracing | | 31.51 |
| | 3. Valves and Fittings | | 86.60 |
| | 4. Porous Stones | | 19.60 |
| | 5. Springs | | 3.20 |
| | 6. Pressure-Vacuum Regulators | | 150.00 |
| | 7. Pressure-Vacuum gauges | | 31.20 |
| | | | $ 484.11 Subtotal |
| Earthquake Simulation Testing | 1. Plastic | One experimental set-up designed & fabricated | $ 55.00 |
| | 2. Metal | | 151.02 |
| | 3. Valves and Fittings | | 174.65 |
| | 4. Seals and Sealants | | 16.65 |
| | 5. Pressure-Vacuum Regulators | | 118.00 |
| | 6. Pressure-Vacuum Gauges | | 37.70 |
| | | | $ 553.02 Subtotal |

| Laboratory Exercise | Item(s) | Quantity | Expenditure |
|---|---|---|---|
| Field Investigation | 1. Sample Bags | 24 | $ 2.00 |
| | 2. Sample Jars | 24 | 18.00 |
| | 3. Equipment Storage Rack | 1 | 240.00 |
| | 4. Blade Auger and Accessories | 1 | 57.00 |
| | 5. Split Spoon Sampler | 2 | 103.00 |
| | 6. Stationary Piston Sampler and Accessories | 1 | 281.85 |
| | 7. Sample Retainer | 2 | 10.30 |
| | 8. Shelby Tubes | 10 | 56.00 |
| | 9. Pulling Plate | 1 | 14.75 |
| | 10. Strap Wrenches | 2 | 44.00 |
| | | | $ 826.90 Subtotal |
| Field Density Test | 1. Sand Cone Density Test Equipment and Accessories | 2 | 97.40 |
| | 2. Rubber Balloon Density Test Equipment and Accessories | 2 | 221.00 |
| | 3. Field Sample Cans | 12 | 9.60 |
| | | | $ 328.00 Subtotal |
| Multipurpose Laboratory Equipment | 1. Timer | 1 | 14.00 |
| | 2. Heavy Duty Solution Balance | 1 | 159.00 |
| | 3. Tools | one set | 206.66 |
| | | | $ 379.66 Subtotal |
| | | | GRAND TOTAL = $5,131.94 |

RESOURCES:

If additional information and/or copies of this document are needed, please contact:

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