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ABSTRACT

This document contains the outlines of each of 34 lectures given in the Earth Control and Investigations course sponsored by the Denver Laboratories. Topics covered include construction control of earth dams, canals, and filters; field and laboratory test procedures; soil classification and logging; and field investigations. (DT)

TRAINING COURSE

- 1974 -

Earth Control and Investigations

BUREAU OF RECLAMATION
ENGINEERING AND RESEARCH CENTER
DENVER, COLORADO

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

ENGINEERING AND RESEARCH CENTER

Denver, Colorado

EARTH CONTROL AND INVESTIGATIONS COURSE

Division of General Research
Earth Sciences Branch
Building 56
Denver Federal Center

February 4 to February 15, 1974

CONTENTS

DESCRIPTION OF COURSE

The Earth Control and Investigations course has been given by the Denver Laboratories during 20 of the past 28 years. The course is presented by the Earth Sciences Branch of the Division of General Research with assistance from the Divisions of Design, Construction, and Planning Coordination. The training is designed to promote consistency and uniformity in control and investigation procedures throughout the Bureau of Reclamation.

This notebook contains the outlines of each lecture and space for note taking. At the end of each outline are study references that you should review before each day's lectures.

On the last day, there will be a panel discussion of any questions you would like to ask. Questions should be deposited in the container at the front of the auditorium.

Three examinations will be given during the course. On Friday, February 8, you will be tested on construction control. On Monday, February 11, a test will be given that covers field and laboratory test procedures. The last examination will be given on Friday, February 15, and will cover soil classification and logging and investigations. The grades of these tests will be reported to your project or your agency and will become a permanent part of your personnel file. Special recognition is given to those students with the highest grades.

EARTH CONTROL AND INVESTIGATIONS COURSE - 1974

Class Schedule

Monday - February 4

Time	Subject	Outline	Instructor
7:30	Registration		A. K. Howard
8:15	Welcome		H. G. Arthur
8:30	Denver E&R Center		H. J. Cohan
8:45	Current Construction Program		W. R. Groseclose
9:00	Design Concepts		J. W. Hilf
9:15	Future Projects		W. W. Reedy
9:30	Introduction to Course		H. J. Gibbs
9:45	Break		
10:00	Construction Control Introduction	1	C. A. Lowitz
11:00	Fundamental Definitions (related to field and lab test procedures)	2	A. K. Howard
11:30	Group Photograph		W. M. Batts
12:00	Lunch		
12:30	Field and Laboratory Test Procedures First Session		
	Field Density	3	R. D. Richmond
	Lab Compaction	4	O. R. Harju
	Standard Properties	5	P. C. Knodel
	Permeability and Settlement	6	J. Merriman
	Rapid Compaction Control	7	G. DeGroot

Tuesday - February 5

7:30	Construction Control - Earth Dams	8	E. W. Gray, Jr. and E. L. McAlexander
9:45	Break		
10:00	Construction Control - Earth Dams Quality Control	9	A. Zlaten
10:30	Responsibilities of Inspectors		C. E. Tackett
11:00	Construction Control - Foundation Grouting		L. R. Gebhart
12:00	Lunch		
12:30	Field and Laboratory Test Procedures Second Session	3-7	

Class Schedule - Continued

Wednesday - February 6

Time	Subject	Outline	Instructor
7:30	Earth Dam Instruments	10	W. W. Daehn
8:30	Earth Dam Instruments - Application of Data	11	R. W. Kramer
9:30	Break		
9:45	Special Laboratory Tests	12	W. Ellis
10:30	Construction Control - Canals and Miscellaneous Structures	13	H. J. Gibbs
12:00	Lunch		
12:30	Field and Laboratory Test Procedures Third Session	3-7	

Thursday - February 7

7:30	Construction Control - Field Laboratories and Reports	14	W. Ellis J. A. Aikele
8:30	Construction Control - Filters	15	C. W. Jones
9:30	Break		
9:45	Soil-Cement - Slope Protection	16	G. DeGroot
11:15	Soil-Cement - Pipe Bedding	17	G. DeGroot
12:00	Lunch		
12:30	Field and Laboratory Test Procedures Fourth Session	3-7	

Friday - February 8

7:30	Construction Control - Examination		A. K. Howard
8:45	Safety Program		R. J. Searle
9:15	Break		
9:30	Film		
10:30	Field Investigations - Introduction to Foundation Requirements	18	H. J. Gibbs
11:00	Field Investigations - Relation to Project Planning	19	G. H. Talbott
11:30	Free Time		
12:00	Lunch		
12:30	Field and Laboratory Test Procedures Fifth Session	3-7	

Class Schedule - Continued

Monday - February 11

Time	Subject	Outline	Instructor
7:30	Field and Laboratory Test Procedures - Exam		A. K. Howard
8:45	Classification and Logging - Geology and Origin of Soils	20	I. E. Klein
9:45	Break		
10:00	Classification and Logging - Geologic Logs of Drill Holes	21	L. R. Burton
11:00	Field Investigations - Field Tests	22	P. C. Knodel
12:00	Lunch		
12:30	Classification and Logging - Classification Introduction -	23	J. P. Bara
	Discussion and Practice	24	Assistants C. T. Coffey L. J. Cox G. DeGroot O. R. Harju P. C. Knodel C. A. Lowitz R. D. Richmond

Tuesday - February 12

7:30	Field Investigations - Exploration Procedures and Sampling Materials	25	R. C. Hatcher
8:30	Classification and Logging - Test Pits and Auger Holes	26	A. Zlaten
9:30	Break		
9:45	Field Investigations - Canals and Miscellaneous Structures - Foundations and Materials	27	C. A. Lowitz
11:00	Field Investigations - Field Permeability Tests	28	C. W. Jones
12:00	Lunch		
12:30	Classification and Logging - Fine-grained soils -	23	J. P. Bara
	Discussion and Practice	24	Assistants

Class Schedule - Continued

Wednesday - February 13

Time	Subject	Outline	Instructor
7:30	Classification and Logging -		
	Coarse-grained Soils -	23	J. P. Bara
	Discussion and Practice	24	Assistants
12:00	Lunch		
12:30	Classification and Logging -		
	Borderline Soils -	23	J. P. Bara
	Discussion and Practice	24	Assistants

Thursday - February 14

7:30	Field Investigations -		
	Sampling Foundations	29	R. C. Hatcher
9:15	Break		
9:30	Field Investigations - Earth		
	Dam Foundations	30	L. W. Davidson
10:30	Field Investigations - Earth		
	Dam Materials	31	E. W. Gray, Jr.
12:00	Lunch		
12:30	Classification and Logging -		
	Undisturbed Soils -	23	J. P. Bara
	Discussion and Practice	24	Assistants

Friday - February 15

7:30	Classification and Logging and		
	Investigations Examination		J. P. Bara
9:30	Rock Mechanics - In situ Testing	32	E. J. Slebir
10:30	Rock Mechanics - Instrumentation (I)	33	W. G. Austin
	Rock Mechanics - Instrumentation (II)	34	J. W. Fabry
11:30	Free Time		
12:30	Lunch		
1:00	Question and Answer Panel		Instructors
2:00	Discuss Examinations		J. P. Bara and A. K. Howard
3:00	Present Certificates		H. J. Cohan

INSTRUCTORS

Aikele, John H.	Engineering Technician Earth Sciences Branch
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SPEAKERS

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H. J. Cohan	Chief, Division of General Research
W. R. Groseclose	Chief, Division of Construction
J. W. Hilf	Chief, Division of Design
R. J. Searle	Chief, Division of Safety
W. W. Reedy	Chief, Division of Planning Coordination
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1974
EARTH CONTROL AND INVESTIGATIONS TRAINING COURSE
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Outline No. 1

CONSTRUCTION CONTROL INTRODUCTION

A. Introduction

B. Types of Laboratories

1. Type C - Large
2. Type B - Medium
3. Type A - Small
   (1) Stationary
   (2) Mobile
4. Vehicle
5. Combinations of types of laboratories

C. Laboratory Equipment

1. Calibration
2. Care and maintenance
3. Use

Study references: Earth Manual

Laboratories	pages 187-190
Laboratory equipment	pages 400-408

Outline No. 2

FUNDAMENTAL DEFINITIONS

A. Introduction

1. Purpose

2. Test procedures to be covered

   a. Field density

   b. Lab compaction

   c. Standard properties

   d. Permeability and settlement

   e. Rapid compaction control

B. Field Density

1. Designation E-24, page 582

2. Density calculations

C. Laboratory Compaction

1. Proctor compaction (cohesive soils), Designation E-11, page 455

   a. Density calculations

   b. Penetration needle calculations

2. Relative density (cohesionless soils), Designation E-12, page 467

   a. Miminum density calculations

   b. Maximum density calculations

   c. Relative density calculations

D. Standard Properties

1. Sample preparations, Designation E-5, page 408
2. Gradation analysis, Designation E-6, page 414
   a. Sieve analysis calculations
   b. Hydrometer analysis calculations
3. Soil consistency tests, Designation E-7, page 426
   a. Liquid limit
   b. Plastic limit
   c. Shrinkage limit
   d. Moisture content calculations
4. Specific gravity, Designation E-10, page 442
   a. Apparent specific gravity calculations
   b. Bulk specific gravity calculations

E. Permeability and Settlement

1. Soils passing No. 4 sieve, Designation E-13, page 474j
2. Soils containing gravel, Designation E-14, page 489
3. Coefficient of permeability and settlement calculations

F. Rapid Compaction Control

1. Designation E-25, page 591
2. Calculations

G. Summary

Outline No. 3

FIELD AND LABORATORY TEST PROCEDURES
FIELD DENSITY TEST
(Designation E-24, Earth Manual)

I. Introduction

A. Replacement methods

B. Definition

C. Uses of test

1. Construction control

2. Investigation work

D. Equipment

1. General equipment

2. Specific equipment - demonstration

3. Discussion of errors (replacement methods)

II. Test Procedure (USBR Method)

A. Preparation for test

1. Equipment

2. Control of minus No. 4 (fine-grained soils containing little or no gravel)

3. Control of minus 3-inch soils (containing appreciable gravel)

4. Calibration procedure - demonstration

B. Field procedure

1. Selection of test site

2. Preparation of area

3. Placement of template

4. Excavation of test hole

5. Measurement of volume of hole

C. Laboratory procedure - cohesive soils (see Earth Manual, page 586, or Drawing No. 101-D-285)

D. Laboratory procedure - cohesionless soils

III. Demonstration of Special Equipment

A. Speedy moisture meter

B. Nuclear moisture - density equipment

IV. Practical Exercise

A. Discussion of data sheets

1. 7-1425 Field Density Record

2. 7-1657 Calibration of Sand Density Test Apparatus and Density Sand

B. Calibration of density sand - class

C. Sample calculations - field density tests

V. Summary

Study references: The following references are found in the Earth Manual, Revised Edition, 1968.

1. Designation E-24, Field Density Test Procedure, pages 582-591

2. Chapter III, Control of Construction, pages 248-251, page 300

3. Practice Problem Handouts

FIELD AND LABORATORY TEST PROCEDURES
COMPACTION, RELATIVE DENSITY

A. Introduction - Compaction

1. Origin

2. Summary of compaction standards

   a. ASTM

   b. AASHO - Standard

   c. AASHO - Modified

   d. Corps of Engineers - Modified (airfields)

   e. USBR - Large scale

   f. USBR - Standard

3. Specifications of equipment

   a. Equipment (calibration)

      (1) Hand equipment

      (2) Mechanical compactors

   b. Soil

4. Test procedure

   a. Mechanics of the test

   b. Moisture determination

      (1) 16 hours at 110° C±

      (2) Size sample

   c. Computation and plotting

   d. Source of error

5. Penetration resistance

   a. Use of the penetrometer

   b. Source of error

   c. Value of the penetration resistance curve

6. Zero air voids curve

   a. Significance of the curve

   b. Computations - Zero air voids curve

7. Materials adaptable to compaction

   a. Processing

   b. Types of curves to expect

8. Value of the compaction test

B. Introduction - Relative Density

1. Origin

2. Specifications

   a. Equipment

   b. Materials

3. Test procedure

   a. Minimum density

   b. Maximum density

4. Calculations and use of nomograph

5. Value of relative density test

Study references: Earth Manual, Designation E-11, Proctor Compaction Test, pages 455-467; Earth Manual, Designation E-12, Relative Density of Cohesionless Soils, pages 467-474

LABORATORY TEST PROCEDURES
SAMPLE PREPARATION, GRADATION, ATTERBERG LIMITS, SPECIFIC GRAVITY

I. Presentation

A. Introduction

B. Sample preparation

1. Visual inspection and classification

2. Synthetic gradation analysis

3. Preparation of composite samples

C. Gradation test

1. Purpose and definition of terms

2. Separation of No. 4 sieve

3. Hydrometer analysis (minus No. 4 material)

4. Mechanical analysis

5. Computation and plotting

6. Interpretation of test results

D. Atterberg limits test

1. Purpose and definition of terms

2. Sample preparation

3. Liquid limit

a. One-point method

4. Plastic limit

5. Plasticity index

6. Shrinkage limit

7. Interpretation of test results

E. Specific gravity test

1. Purpose and definition of terms

2. Sample preparation

3. Test procedure for minus No. 4 material

4. Test procedure for plus No. 4 material

II. Review

A. Answer student questions

B. Summarize main topics

Study references: Earth Manual, Designation E-5, Preparation of Soil Samples for Testing, pages 408-414; Designation E-6, Gradation Analysis of Soils, pages 414-426; Designation E-7, Soil Consistency Tests, pages 426-437; Designation E-10, Specific Gravity of Soils, Aggregate, pages 442-453

FIELD AND LABORATORY TEST PROCEDURES
PERMEABILITY AND SETTLEMENT OF SOILS

I. Introduction

A. Types of permeability tests

B. Purpose of test

1. Determination of coefficient of permeability

2. Determination of percent consolidation

C. Principle

1. Darcy's Law

2. Ranges of permeability

3. Standard overburden loads

II. Test Procedure - Standard Test

A. Apparatus

1. Equipment

2. Calibration of constant-head tank

B. Preparation of sample

1. Data needed before test

2. Moisture

C. Placing of specimen

1. Check preparation sheet and compute data for packing

2. Check equipment

3. Ring readings

4. Placing specimen

5. No-load readings

6. Loading

D. Application of water to sample

1. Procedure

2. Readings

E. Sample removal

1. Final readings (loaded)

2. Rebound

3. Penetration resistance needle test

4. Moisture

III. Test Results

A. Calculations

1. Coefficient of permeability

2. Settlement due to saturation

B. Sources of error

1. Piping

2. Entrapped air and foreign matter

3. Temperature

4. Permeability of apparatus

5. Validity of Darcy's Law

C. Reporting results in L-29 report

IV. Other Laboratory Permeability Tests

A. Undisturbed samples

B. Nonloaded soil specimens

C. Soils containing gravel

Study references: All of the references below are contained in the Earth Manual:

Chapter I, Section 21, pages 60-65, Permeability; Chapter III, Section 62, pages 218-220, Permeability; Designation E-13, pages 474-489, Permeability and Settlement of Soils; Designation E-14, pages 489-492, Permeability and Settlement of Soils Containing Gravel

FIELD AND LABORATORY TEST PROCEDURES
RAPID COMPACTION CONTROL

A. Introduction

1. Provides a means of construction control for fine-grained soils which is accurate and can normally be performed in 1 to 2 hours.

   a. Density control - degree of compaction (percent of maximum dry density) is precisely determined.

   b. Moisture control - difference from optimum is determined to a satisfactory degree of accuracy.

2. Density and moisture conditions must be compared to standards to confirm that the field conditions are similar to those assumed during design.

B. Theory

1. Dry density determination based on oven moisture determination which requires 16 to 24 hours.

2. Rapid method control based on relating all densities to the wet density at fill water content.

3. Red line corrections for moisture control based on moisture and density characteristics of average soils. These corrections are necessary since water contents added are based on wet weights rather than dry weights.

C. Practice Problems

1. Symbols

   Fill wet density (pcf) γw_f

   Cylinder wet density (pcf) γw_c

   Maximum density point of converted wet density curve (pcf) γm

   Fill water content (%) w_f

   Optimum water content (%) w_o

Ratio of fill dry density to maximum laboratory dry density (Degree of Compaction) D

Ratio of fill dry density to cylinder dry density at same water content C

Difference between optimum water content and fill water content $w_o - w_f$

2. Outline of problem method

   a. Perform fill density test and screen material through No. 4 sieve to find fill wet density (γw_f).

   b. Compact material at fill water content by standard laboratory test procedure to find cylinder wet density at fill water content (γw_c).

   c. Add 2 percent water to sample of material at fill water content, compact by laboratory test procedure. Divide wet density by 1.02 (1 + water added expressed as a decimal) to find density at fill water content.

   d. If second point has higher converted wet density, add 4 percent water and proceed as in (c.). Divide by 1.04 to obtain converted wet density.

   e. If second point has lower converted wet density, allow material at fill water content to dry until it has lost 2 percent water. Compact and convert to density at fill water content. Divide by 0.98 to obtain converted wet density.

   f. Three points are sufficient if left and right points have lower converted wet densities than center point. Use Y_2-Y_4 method.

   g. If second point has lower converted wet density than point at fill water content but is within 3 pcf, add 1 percent water to soil at fill water content, compact and convert to density at fill water content. Use Y_1-Y_2 method.

3. Example problems

   a. Chart methods

      (1) Y_2-Y_4 method used with even 2 percent moisture spread. Letter points from left A, B, and C.

Values in chart give ordinates of the maximum density point of the converted wet density curve from Point A.

(2) Y_1-Y_2 method used with even 1 percent moisture spread (eliminates need for drying back if converted wet density of point with 2 percent added water is lower in density but within 3 pcf of point at fill water content).

(a) Number points in order in which they were run (i.e., Point (1) at fill water content, Point (2) with 2 percent water added, Point (3) with 1 percent water added).

(b) Values in chart give ordinates of the maximum density point of the converted wet density curve from Point (1).

(c) If the ratio of Y_1/Y_2 is greater than 0.38 or if the Zm obtained from the chart is less than -1.0, this method is not considered applicable. In that case, a dry back point should be obtained and the problem solved by Y_2-Y_4 method.

b. Graphical methods - outlined on cover sheet

(1) Can be used on all problems but is more time-consuming than chart methods.

(2) Must be used if uneven moisture spread is obtained.

c. Both chart and graphical parabola methods assume that the compaction curve can be approximated by a parabola whose axis is vertical.

4. Calculations

a. Rapid control method

$$C = \frac{\text{Fill wet density } (\gamma w_f)}{\text{Cylinder wet density of material at fill water content } (\gamma w_c)}$$

$$D = \frac{\text{Fill wet density } (\gamma w_f)}{\text{Maximum density point of converted wet density curve } (\gamma m)}$$

$w_o - w_f$ = Added water at Point A + xm + red line correction

b. For record purposes after fill water content has been determined w_f = fill water content expressed as a decimal (e.g., 10% = .10)

Fill dry density = Fill wet density $(\gamma w_f/(1+w_f)$

$$\text{Lab max dry density} = \frac{\text{Maximum density point of converted wet density curve } (\gamma m)}{(1+w_f)}$$

$$\text{Cylinder dry density} = \frac{\text{Cylinder wet density of material at fill water content } (\gamma w_c)}{(1+w_f)}$$

Optimum water content = w_f + $(1+w_f)$(added water at maximum density point)

5. Class exercise

a. Test apparatus

b. Rapid compaction test

c. Computations and discussion

Study references: Earth Manual, Designation E-25, pages 591-613
Engineering Monograph No. 26
Practice Problems Handout

CONSTRUCTION CONTROL - EARTH DAMS

A. Introduction

1. Importance of construction control
2. Control related to investigation and design
3. Comparison of soils with other construction materials
4. History of earthwork control
5. The modern concept

B. Foundations

1. Types
2. Control of treatment
3. Dewatering

C. Impervious Zones (Rolled Earthfill)

1. Criteria of satisfactory impervious zones
2. Control features of each criterion
3. Moisture and density control
4. Types and frequency of tests

D. Compacted Pervious Zones

1. Criteria of satisfactory pervious zones
2. Control features of each criterion
3. Moisture and density control
4. Types and frequency of tests

E. Riprap and Rockfill

1. Criteria of satisfactory riprap and rockfill

2. Control features of each criterion

F. Summary

Study reference: Earth Manual, Chapter III, Parts A, B, C, D

CONSTRUCTION CONTROL - EARTH DAMS
QUALITY CONTROL

A. Reporting Tests

1. Forms

2. Reports

B. Analysis of Field Control Tests

1. Design recommendations

2. Summary of quality control.

Outline No. 10

EARTH DAM INSTRUMENTATION

A. Types of Instruments and their Purpose

1. Pressure measurement apparatus - pore water pressure

   a. Dams

   b. Structures

2. Internal movement apparatus

   a. Vertical movement devices

   b. Horizontal movement devices

   c. Foundation settlement, baseplate devices

3. Surface measurement points

   a. Embankments

   b. Structures

   c. Land movements

4. Seismic apparatus

   a. Accelerographs

   b. Seismic - seismographs

B. Description of Apparatus

1. Twin-tube piezometers

2. Porous-tube piezometers

3. Internal movement apparatus

   a. Vertical movement (crossarm) devices

   b. Horizontal movement devices

4. Foundation settlement (baseplate) devices

5. Measurement points

   a. Embankments

   b. Structures

6. Seismic

   a. Accelerographs and seismographs

C. Materials for Instrument Installations

1. Purchase by Government for Government installation

2. Purchase by Government for contractor's installation

3. Purchase and installation by contractor

D. Installation of equipment by

1. Government forces

2. Contract specifications

   a. Prime contract

   b. Special contract or extra work order

   c. Supplemental contract

E. Reports Required on Installations

1. During construction - progress report - monthly - L-15

2. At completion of construction ---------- L-16

3. At scheduled intervals - periodic ---------- L-23

F. Quality of Data Obtained

1. Care during installation

2. Maintenance of recording apparatus

3. Possible failure of equipment

G. Forms Used for Reporting Data on Instrument Installations

1. 7-1346, 7-1347, 7-1348, 7-1355, 7-1355A, 7-1359, 7-1600, and special forms

H. Suggestions for Improving Apparatus

1. Field reports on malfunction of equipment

2. Field suggestions for design changes

3. Awards

Study references: Earth Manual, pages 258-264, Designations E-27 to E-35

EARTH DAM INSTRUMENTS - APPLICATION OF DATA

I. Why Instrumentation?

   A. Verify design assumptions

   B. Monitor structure for potentially dangerous conditions

II. Instruments and Information

   A. Movements

      1. Internal vertical movement (crossarm) device

      2. Internal horizontal movement device

      3. Surface measurement points

      4. Deflectometer

      5. Foundation settlement baseplate

   B. Pressures

      1. Twin-tube piezometers

      2. Porous-tube piezometer

      3. Standpipe

   C. Seepage

      1. Flow-measurement devices

      2. Reservoir level gage

      3. Pressure measurement devices in B

   D. Earthquake effects

III. Examples of Applications

IV. Data Collection (more than filling out forms)

V. Summary

SPECIAL LABORATORY TESTS

A. Introduction

The special tests of the laboratory are described to acquaint the field personnel with the facilities of the laboratory and how the materials sent from the field are studied.

B. Consolidation Test

1. Purpose and use in undisturbed soils and in disturbed soils
2. General discussion of the principle
   a. Load - consolidation
   b. Time - consolidation
3. Sample preparation and equipment operation
4. Results obtained
5. Permeability testing
6. Use for expansion determination

C. Shear Tests

1. Purpose and use in undisturbed soils and in disturbed soils
2. General discussion of the principle
3. Equipment available and types of tests
   a. Equipment: small, medium, and large
   b. Special features of the equipment
   c. Unconfined compression test
   d. Adaptations of standard shear tests with comments on the purpose

D. Earthquake Test

1. Purpose of test and applications

2. Equipment and operation

3. Evaluation of results

Study references: Earth Manual, Designation E-15

CONSTRUCTION CONTROL - CANALS AND MISCELLANEOUS STRUCTURES

Note: All references are to pages in the Earth Manual.

A. Introduction - Ref. Part C, pages 212-228 and Parts E and F, pages 274-325.

Purpose of this lecture is to discuss basic techniques and fundamentals for examining and controlling quality in foundations and miscellaneous earth structures.

B. Basic soil types and problems concerning foundations (Reference: "Engineering Use Chart," Figure 8, page 23).

1. Clays - (1) firm consolidated, (2) compressible, (3) expansive

2. Silts and low plasticity clays - (1) low density and (2) dense

3. Sands and coarse-grained soils - (1) denseness and (2) permeability

4. Rock and formation material

C. Inspection of Foundations

1. Methods of inspection and engineering guidelines

2. Protection against disturbance

3. Awareness of foundation discontinuities

4. Effect of saturation - (1) collapse, (2) expansion, (3) strength loss

5. Seepage and piping

6. Piles and caisson foundations

D. Considerations for Canal Subsoils

1. Seepage

2. Erosion

3. Ground water

E. Consideration for Pipeline Subgrades

F. Control Criteria of Special Interest

1. Expansive clay - Reference: pages 226-227
   Discussion of Table 3, page 227

2. Collapsing soil - Reference: pages 222-226

   a. Discussion of Figure 82, page 225

   b. New chart of density versus liquid limit

3. Other uses of the density versus liquid limit chart

   a. Trends of recompacted soil

   b. Soft saturated and sensitive soils

   c. Experience with expansive soil - New ideas of controlling by moisture content

4. Criterion for selecting well-graded backfill (References: Figure 103, page 293).

   a. Variations of fines

   b. Variations described in ASTM: D 1241 and our use for surfacings and subbase.

5. Recommended relative densitiy limiting requirements for granular material (Reference: page 313).

6. Discussion of pile-driving formulas and estimating length from penetration resistance test (Reference: pages 316-318).

7. Comment of frost action limitations (Reference: page 69).

8. Guideline for use of relative density control versus Proctor compaction. Also these guidelines are related to vibratory compaction as opposed to roller compaction (Reference: page 321 and Table 5, pages 287-291).

9. Latest criteria for canal cross section (Reference: Figure 100, pages 280-281).

10. New chart for recommendations of desirable earth canal lining material.

TYPES OF INFORMATION USEFUL FOR VARIOUS SOILS

Sands & Gravels

- Penetration Resistence
- Gradation
- Density
- Relative Density

Silts & Low Plasticity Clays

- Penetration Resistance Moisture Important & Moisture Change Must Be Considered
- Density + Moisture
- Liquid Limit
- Gradation
- Undisturbed Samples for Laboratory Testing

Clays & High Plasticity Clays

- Penetration Resistance to Show In Place Firmness
- Density + Moisture
- Liquid Limit
- Plasticity Index
- Shrinkage Limit
- Gradation with Colloid Content for Expansion Question
- Vane Test In Soft Saturated Soil with Penetration<10 Blows
- Undisturbed Samples for Laboratory Testing

CONSTRUCTION CONTROL - FIELD LABORATORIES AND REPORTS

A. Introduction - Inspection (Ref. Art 49, page 185)
Discuss intent of this lecture.

B. Field review of field laboratories and why they are made.
Annual report of field laboratory survey.

1. Basic information furnished

2. Special instructions regarding forms

3. What is done with the report

C. Construction Control Reports (Ref. Art 51, page 190)

1. Purpose

2. Scope of reports (Ref. Reclamation Instruction, Part 175, "Records of Construction and Structural Behavior, Chapter 1, Periodic Reports," Paragraph 175.1, 12)

a. Narrative - What is wanted.

b. Summary of control data

(1) Form 7-1581A - Consolidated Earthwork (relative density)

(2) Form 7-1581B - Consolidated Earthwork (Proctor compaction)

(3) Form 7-1737 - Compacted soil-cement

D. Type of Compaction Specifications

1. Method - Review Table 5, page 287

2. Performance

E. What We Do With Control Reports

1. Initial review of L-29 reports

2. Monthly summary

3. Followup inquiries

4. Guidelines of testing frequency requirements and reworked tests (refer to page 300)

CONSTRUCTION CONTROL - FILTERS

A. Purpose of filters is to relieve seepage pressures in soil foundations and structures and carry off detrimental water.

B. Uses of filters are: (a) pervious blankets or drains under canal linings, spillways, or dam aprons; (b) intercepting or subsurface drains; (c) toe drains in earth dams or levees; and (d) weighted filters on critical areas subject to seepage pressures.

C. Component parts are base materials (foundation soils), one or more pervious filter layers with or without open-jointed or perforated pipe.

D. General requirements are that voids in filter be sufficiently small to prevent penetration by base material but sufficiently large and interconnected to readily transmit seepage water. Pipe joints or perforations small enough to prevent infiltration of filter material.

E. Filter criteria are based on results of laboratory filtration tests on typical base and filter materials. USBR filter tests (including preliminary tests on crushed rock) described in report in EM-425 (1955).

F. Selection of filter material is based primarily on grading of filter material in relation to grading of base material. For this purpose certain percent sizes are established for use in controlling the grading of the filter material within limits on these sizes.

G. As an example of a given percent size the 50 percent size is shown on the standard gradation test sheet as the particle size (abscissa), corresponding to the point where the grading curve intersects the 50 percent finer line of the ordinate. It is the size in a soil sample such that 50 percent by weight of the sample contains larger particles and 50 percent contains smaller particles.

H. USBR Filter Test Criteria

1. General

   a. The maximum size of material should be 3 inches.

   b. Not more than 5 percent should pass the No. 200 sieve.

   c. For base materials containing more than 10 percent plus No. 4 and more than 10 percent of minus No. 200 material, the filter grading should be selected on the basis of the minus No. 4 fraction of the base material.

   d. The maximum size of pipe openings or perforations should be one-half the 85-percent size of the adjacent filter material.

2. Natural subrounded materials

   For uniform grain size filter material

$$\frac{\text{50\% size of filter material}}{\text{50\% size of base material}} = 5 \text{ to } 10$$

   For graded filter materials

$$\frac{\text{50\% size of filter material}}{\text{50\% size of base material}} = 12 \text{ to } 58$$

   and

$$\frac{\text{15\% size of filter material}}{\text{15\% size of base material}} = 12 \text{ to } 40$$

3. Crushed rock (tentative criteria)

$$\frac{\text{50\% size of filter material}}{\text{50\% size of base material}} = 9 \text{ to } 30$$

   and

$$\frac{\text{15\% size of filter material}}{\text{15\% size of base material}} = 6 \text{ to } 18$$

I. Construction Recommendations

1. Base material should be lightly compacted and all holes filled.

2. Segregation of filter material should be minimized by moistening and careful placement procedures.

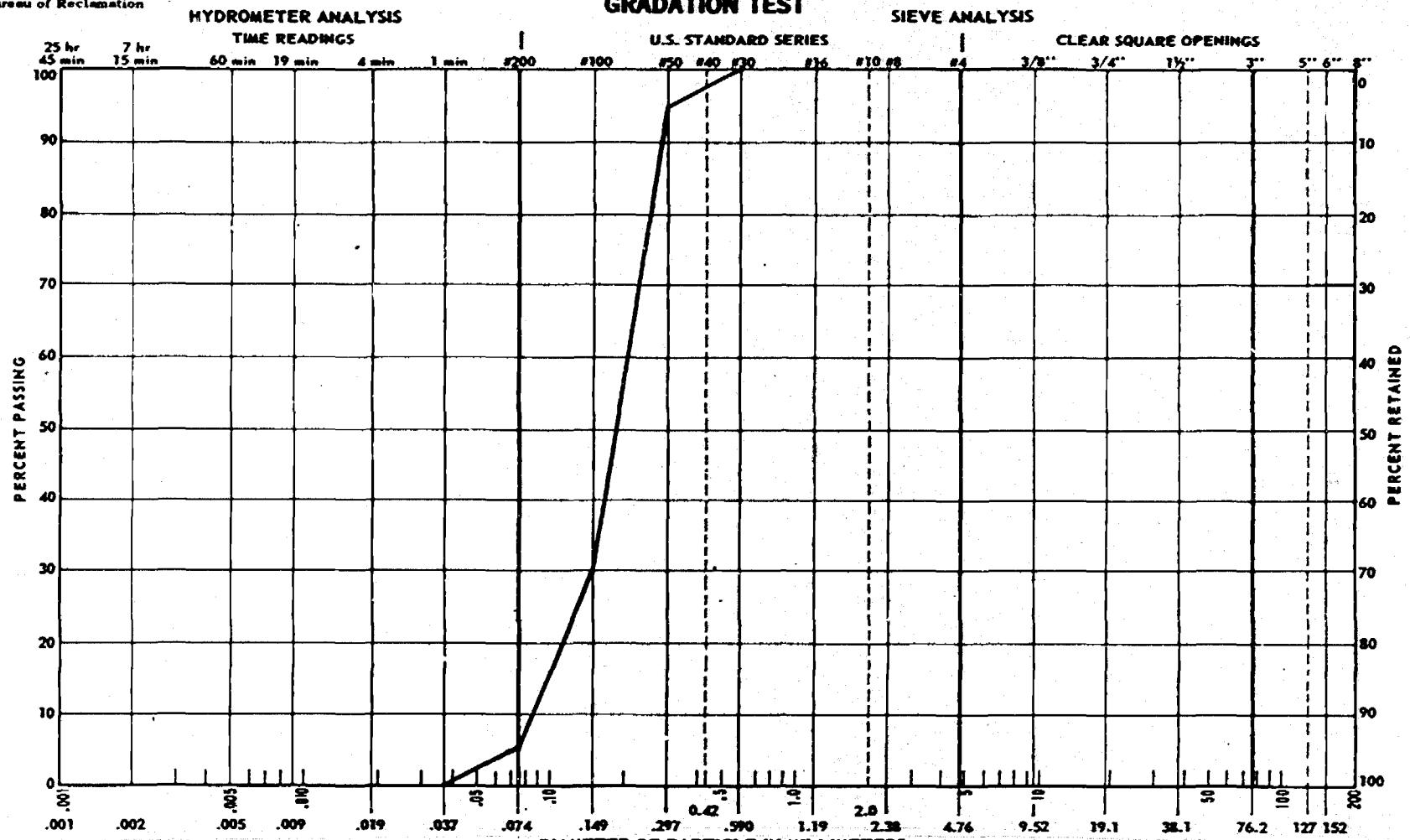
3. Filter materials should be compacted.

4. Infiltration of filter material into drainpipe during filter placement should be prevented.

Study reference: Earth Manual, pages 322-325

1415 (8-70)
Bureau of Reclamation

GRADATION TEST



FINES	SAND			GRAVEL		COBBLES
	FINE	MEDIUM	COARSE	FINE	COARSE	

CLASSIFICATION SYMBOL _____

Gravel _____ %

Sand _____ %

Fines _____ %

ATTERBERG LIMITS

Liquid Limit _____ %

Plasticity Index _____ %

Shrinkage Limit _____ %

SPECIFIC GRAVITY

Minus No. 4 _____

Plus No. 4

Bulk _____ Apparent _____

NOTES _____

SAMPLE NO. _____ HOLE NO. _____ DEPTH _____ ft (_____ m)

FIGURE

SOIL-CEMENT SLOPE PROTECTION

A. Used as slope protection on earth dams as a substitute for rock riprap

1. Cost of slope protection can be less with soil-cement since rock is scarce and costly in some areas.

2. Use of soil-cement Should be investigated if rock is more than 20 miles away.

3. Local soils can normally be utilized with the addition of 8 to 14 percent cement by dry weight of soil.

B. Historical Background. - Soil-cement had been used extensively in highway work for years.

1. Bonny Test Section using two soils was constructed in 1951.

   a. Mixed-in-place construction procedures were used.

   b. Soil-cement was placed in horizontal layers in a stair-step fashion up the slope.

2. Eight major Bureau of Reclamation structures have been faced with soil-cement since 1963 using a total of 670,000 cubic yards of soil-cement.

3. In addition, the Portland Cement Association lists 62 other structures faced with soil-cement. Volumes of these facings range from 1,000 to 250,000 cubic yards.

4. Bid prices range from $5 to $12 cubic yard with most of the bids in the $6 to $9 per cubic yard range.

C. Material and Cement Content Selection

1. Gradation. - Preferred gradation is fairly well graded.

   a. Well-graded materials require less cement.

   b. Durability of individual grains checked by less violent dispersion action.

   c. Deposits which contain lenses of clay should be avoided.

2. Compaction. - Material should compact to dense mass.

   a. Significant increase of density at increase of cement content may indicate use of cement to fill voids.

   b. Compaction test is used as a basis for placing test specimens.

3. Durability Tests. - Used to evaluate resistance of soil-cement to weathering - ASTM test procedures.

   a. Specimens are placed similar to compaction tests, using 0.033-cubic-foot mold.

   b. Specimens are used for 7 days at 100 percent humidity and 70° F (fog room curing).

   c. Wet-dry tests are wetted for 5 hours and dried at 160° F for 43 hours.

   d. Freeze-thaw tests are frozen 24 hours, thawed in fog room for 24 hours.

   e. Specimens are brushed with wire brush after each cycle and a total of 12 cycles are performed. Total loss is expressed as a percentage.

   f. Design criteria. - 6 percent max loss for wet-dry tests and 8 percent for freeze-thaw tests.

4. Compressive Strength Tests. - Used mainly as an indirect measure of equality.

   a. Specimens are placed in 2.83- by 5.67-inch molds, 3-, 7-, 28-, and 90-day tests.

   b. Specimens are cured in fog room with 4- to 24-hour soaking period in water before testing.

   c. Ends are capped with sulfur and tested at a rate of 20 psi/sec.

   d. Design criteria. - 600 psi minimum for 7-day specimens, 875 psi minimum for 28-day specimens.

5. Compaction, Water Content, and Time Delay Effects

   a. Increase of density usually increases quality.

   b. Highest quality is usually obtained from 2 percent dry to optimum water content.

   c. Due to cement-water reaction, quality decreases with time delays; delays of 1 to 2 hours are usually not too critical.

D. Construction Procedures

1. Material must be excavated and stockpiled in such a fashion that a consistent material is fed to the mixer.

2. Soil and cement must be proportioned correctly prior to mixing.

   a. Reciprocating plate feeder has been the most successful device for soil feed.

   b. Surge hopper with vane feeder is used to proportion the cement.

   c. Both devices must be calibrated at start of construction and checked occasionally.

   d. Soil and cement are mixed with pugmill mixer and sufficient water is added during the mixing to bring the soil-cement to the desired water content.

3. Mixed soil-cement is transported to the placement area with trucks.

   a. Soil-cement is spread to a uniform loose lift with dozer-mounted spreader.

   b. Thirty-minute time limit from mixer to spreader on fill.

   c. Approach ramps must be adequate to protect previous layers.

   d. Slope of up to 8:1 on placement is permitted to increase working width.

4. Material is compacted with a combination of sheepsfoot and pneumatic-tired rolling.

   a. Lower portion of lift is compacted with sheepsfoot roller. Roller weight is adjusted until it begins to walk out.

   b. Upper portion of lift is compacted with pneumatic-tired roller. Roller weight is adjusted until it does not cause significant lateral movement of the soil-cement.

   c. Time limits between each operation are 30 minutes.

5. Curing is usually accomplished by sprinkling.

   a. Use of excessive water may be detrimental.

   b. Water should be applied in a fine fog-type spray.

   c. Smooth compaction plane is removed by brooming and brooming is usually repeated to clean lift for next layer.

E. Construction Control Procedures

1. Gradation, specific gravity, and Atterberg limits tests are run on soil.

2. Soil and cement feed are calibrated by timing feeds separately.

   a. Soil feed is checked by timing truckload during production and using cement feed calibration to determine soil weight.

   b. Cement feed is usually quite consistent in a well designed plant.

   c. Moisture contents are determined by "quick" methods during calibration.

3. Sample of soil-cement is obtained prior to compaction.

   a. Laboratory compaction is performed at about the same time as compaction on the placement to account for time dependency of soil-cement.

b. Fill density test is performed as soon as possible after compaction near the spot from which soil was taken.

c. Unconfined compression specimens placed to density found in fill density test.

d. One test for every 500 cubic yards placed.

4. Chemical cement content determinations can be made if soil source is low in calcium.

5. Construction control data is reported on Form No. 7-1737.

F. Record Coring

1. One core hole for every 5,000 cubic yards.

a. Unconfined compression and durability tests performed on representative pieces.

b. Comparisons with data from design tests indicate whether material meets design requirements.

c. Core holes usually filled with grouted anchor bar to provide quick reference for future inspections.

G. Portland Cement Association film "Soil-Cement Slope Protection for Earth Dams."

PLASTIC SOIL-CEMENT PIPE BEDDING

I. Introduction

A. First used by Bureau of Reclamation on Canadian River Project.

B. Conclusions of research done by American Pipe and Construction Company.

1. The soil-cement backfill should be used only if the soil can give adequate support for the pipe and trench backfill.

2. The cradle trench and soil-cement backfill eliminate large quantities of excavation and recompaction.

3. The soil-cement backfill provides uniform transfer of load to the soil foundation.

4. The most suitable soil types for soil-cement are sands and silty sand.

5. The total water requirement is a function of the percent fines and grain-size distribution within the material being used.

6. Cement requirements should be based on strength and durability requirements for the bedding.

7. Seven-day compressive strengths of 50-psi minimum can normally be obtained with 2 to 3 sacks of cement for each cubic yard of bedding material.

8. Cement and water should be premixed before adding to the soil.

9. A noncohesive soil can be mixed satisfactorily in a drum-type mixer.

II. Comparison of Bedding Methods and Materials Used

A. Conventional Bedding

1. Trench excavated to bottom of pipe

2. Material placed around pipe to specified depth

   a. Consolidated to 70 percent relative density for free-draining material

   b. Compacted to 95 percent of Proctor maximum dry density for fine-grained material

3. This method often requires considerable labor.

B. Plastic Soil-cement Pipe Bedding

1. Trench excavated to depth corresponding to top of bedding - springline elevation. (Depth of bedding depends on design of pipe.)

2. Remainder of trench is excavated as semicircular section 4 to 6 inches greater in diameter than the outside diameter of the pipe.

3. Pipe sections are supported about 2 inches above the trench bottom on sand pads.

4. Annular space filled with plastic soil-cement.

5. This method eliminates the excavation and recompaction of the block of material between the springline and bottom of the pipe. It also is a fairly mechanized procedure.

6. Material and cement content selection

   a. Unconfined strength must be high enough to transfer pipe load to foundation (50-psi minimum usually desired).

   b. After placement and initial set, volume change should be fairly small.

   c. After set, material should be durable through moisture changes.

   d. Sandy materials with less than 10 percent fines are usually suitable with about 10 percent cement by weight.

   e. Strengths over 500 psi are not desirable as bedding might alter shape of pipe.

III. Field Test Section

A. Installation. - Four sections of pipe installed using four different soils for bedding material. Each soil had 2-1/2 sacks of cement per cubic yard.

1. Mortar sand - fairly well-graded material with 8-1/2 percent cement by weight.

2. Blow sands - uniform fine sands with 10 percent cement by weight.

3. Blow sands - uniform fine sands with 10 percent cement by weight.

4. Lean clay - medium plasticity fine-grained material with 11-1/2 percent cement by weight.

B. Curing. - Pipe sections left in place 7 days.

C. Measurements and Observations of Exposed Bedding Materials.

1. Changes of diameter after exposure were small.

2. Exposed bedding showed that good contact had been obtained.

3. All materials seemed to perform well but lab testing showed clay material was not durable.

IV. Construction Control

A. Gradation. - Percentage fines and organic material controlling factors.

1. Maximum of 10 percent fines usually specified.

B. Compressive Strength. - Adequate compressive strength to insure firm support required.

1. Companion compressive strength specimens should be formed for each 400 feet of pipe or at least twice per shift.

a. Bedding material should be placed without consolidation.

b. Tested after 7 days curing

2. Some specimens should be subjected to wet-dry cycles to determine whether they are durable.

C. Batching. - Batching by weight preferred to provide more consistent results.

1. Water-cement ratio maximum usually specified as 3.5.

a. Water-cement ratio must be low enough to form a fluid which will maintain sand in suspension.

2. Fluidity of mix checked by timing flow from a special funnel.

a. Funnel has 6 inches top diameter, 4-1/2 inches high with 11/16-inch opening.

b. Flow time to empty funnel should be 5 to 8 seconds to insure that material can be pumped and will fill space completely.

V. Summary

A. Cost reduction possible due to amount of excavation and compaction which is eliminated.

B. Should be used only if the in-place soils can give adequate support to the pipe.

FIELD INVESTIGATIONS - INTRODUCTION TO FOUNDATION REQUIREMENTS

Note: References are to pages in the Earth Manual.

A. Introduction

Discussion of soil mechanics in investigating foundations and the effect of foundation characteristics on the design of the structure.

B. Basic Soil Mechanics Criteria for Analyses

1. Settlement must be within allowable limits.

2. Foundations must be safe against shear failure.

3. Specialized hydraulic structures require limitations in permeability.

C. Foundation Problems

1. Exploration requirements - Reference: Figure 40, page 114; Figure 42, page 117.

2. Bearing capacity - Reference: page 212.

3. Stability - Reference: pages 213-216.

4. Permeability - Reference: pages 218-220.

D. Examples of Foundations With Respect to Soil Types. (Reference: pages 221-228.)

1. Clays

a. Firm consolidated clays

b. Compressive clays

c. Expansive clays

2. Silts and intermediate soils

   a. Low-density deposits

   b. Normal, intermediate soil characteristics

3. Sands and coarse-grained soils

   a. Importance of density

   b. Desirable effects of gravel

4. Solid rock foundation

E. Discussion of Criteria for Evaluating Penetration Resistance

FIELD INVESTIGATIONS - RELATION TO PROJECT PLANNING

A. Introduction

1. Necessity for project investigations

2. Stages of investigation: Regional or basin planning, appraisal, feasibility, preconstruction

B. Project Plan Formulation - Multiobjective Planning

1. Concepts of plans

2. Alternatives

3. Environmental considerations

4. Incremental analyses

5. Evaluating Plans

6. Cost Sharing and Repayment

C. Earth Control Investigations

1. Dams

   a. Site-type relationships

   b. Foundations, materials, and seepage

   c. Spillway and other structural features

2. Canals, pipelines, and drains

   a. Excavation materials

   b. Stability, hydraulics, seepage, and lining

3. Tunnels

   a. Excavation materials and construction methods

   b. Pressures, support, lining

4. Structures

   a. Foundations

D. Surveying and Mapping

1. Control topography, strip topography, fly lines

2. Uses: Land classification, layout, location of drill holes, etc.

3. Use of modern USGS quad sheets

4. Force account versus contracts

E. Explorations

1. Exploration required for each level of investigations

2. Force account versus contracts

3. Methods of exploration

   a. Surface inspection

   b. Photo and remote sensor interpretation

   c. Pits and trenches

   d. Auger boring

   e. Drilling

   f. Geophysical methods - electric logging, resistivity, and seismic

Study references: Earth Manual, Chapter I, Properties of Soils; Chapter II, Investigations

Outline No. 20

CLASSIFICATION AND LOGGING
GEOLOGY AND ORIGIN OF SOILS

A. Introductory Remarks

1. The broad range of geologic conditions covered by the term "earth materials" or "soil."

2. The geological services of the Bureau.

B. Weathering and Erosional Processes

C. Examples of Earth Materials and Geologic Environments Involved in Bureau Projects: Slide talk based on several projects - completed, under construction, or proposed - illustrating investigations and operations of borrows with various geologic backgrounds.

D. Sources of geologic information useful for earth materials exploration and testing.

E. Summary

CLASSIFICATION AND LOGGING
GEOLOGIC LOGS OF DRILL HOLES

A. Use of Geologic Data in Engineering Operations

B. Reporting of Data

1. Purpose
2. Logs, sections, narrative
3. Standard forms
4. Ground-water levels
5. Soil classification symbols
6. Depth of exploration holes
7. Method of accomplishing exploration holes
8. Physical description of material
9. Name of material
10. Miscellaneous

FIELD INVESTIGATIONS - FIELD TESTS

A. Standard Field Penetration Test, Designation E-21, Earth Manual, page 574

1. Purpose of test
2. Test procedure and requirements
3. Results
4. Use of data

B. In-place Vane Shear Test, Designation E-20, Earth Manual, page 562

1. 1 to 4 above

C. Methods for Determining In-place Density and Moisture

1. Hand methods
   a. Undisturbed block, Designation E-2, Earth Manual, page 346
   b. Undisturbed cylinder, Designation E-2, Earth Manual, page 346
   c. Field density method, Designation E-24, Earth Manual, page 582
   d. Auger method, Designation E-23, Earth Manual, page 579
2. Mechanical methods, Designation E-2, Earth Manual
   a. Thin-wall drive samplers
   b. Double-tube samplers
   c. Core samplers
3. Nuclear method

Study reference: Earth Manual, Designations E-2, 20, 21, 23, 24

CLASSIFICATION AND LOGGING SOIL
CLASSIFICATION - INTRODUCTION

A. Introduction

1. Unified system, differences from other standards
2. Importance to engineers

B. Soil Components

1. Size
   a. Gravel (G)
   b. Sand (S)
   c. Silt and clay (M and C)
   d. Organic (O)
2. Gradation (W or P)
3. Particle shape - Angularity
4. Moisture

C. Classification of Soils

1. Field
2. Laboratory

D. Engineering Characteristics of Soil Components

E. Soil Descriptions

F. Engineering Comparisons of Soil Groups

G. Summary

Study reference: Earth Manual, pages 1-23, Designation E-3

CLASSIFICATION AND LOGGING CLASSIFICATION - DISCUSSION AND PRACTICE

A. Clean, Coarse-grained Soils (GW, GP, SW, SP)
Study references: Earth Manual, pages 379-388, 396-397

B. Fine-grained Soils (ML, CL, OL, MH, CH, OH, PT)
Study references: Earth Manual, pages 388-394, 398-400

C. Coarse-grained Soils with Fines (GM, GC, SM, SC)

D. Borderline Soils

1. Well or poorly graded (GW-GP)
2. Gravel-sand mixture (GW-SW)
3. Clean or dirty (GP-GM)
4. Coarse or fine grained (GM-ML)
5. Silt or clay (ML-CL)

Study references: Earth Manual, pages 16-18, 387, 393, 397, 400

E. Classification of Undistrubed Samples

Study references: Earth Manual, pages 385, 394, 395
Unified Soil Classification System
(Supplement to the Earth Manual)

FIELD INVESTIGATIONS - EXPLORATION PROCEDURES

A. Introduction

B. Exploration Methods

1. Accessible methods of exploration

   a. Trenching

   b. Cuts

   c. Test pits

   d. Accessible boring

   e. Accessible caissons

   f. Tunnels and drifts

   g. Blasting

2. Nonaccessible methods of exploration

   a. Auger boring (hand and power)

   b. Hollow-stem auger

   c. Enclosed flight auger

   d. Drive-tube boring

   e. Percussion (churn) drilling

   f. Jetting

   g. Wash boring

   h. Rotary drilling

   i. Continuous sampling

C. Other Indirect Methods (only mentioned)

Study reference: Earth Manual, Chapter II, pages 133-154

FIELD INVESTIGATIONS - SAMPLING MATERIALS

A. Introduction - Purpose

B. Disturbed Samples - Types, shipping containers, moisture-content determination and records

C. Sampling Procedure

1. Sampling from accessible holes

2. Sampling from nonaccessible holes

a. Holes smaller than 8 inches

b. Holes larger than 8 inches

3. Sampling stockpiles

D. Logging and Data

E. Sample Size Requirements

F. Shipping Instructions

Study reference: Earth Manual, Designation E-1

Outline No. 26

CLASSIFICATION AND LOGGING LOGS OF TEST PITS AND AUGER HOLES

A. Introduction

1. Definition

B. Purpose of Log

1. Structures

2. Borrow areas

C. The Log Form

1. Percentage by volume of oversize

2. Natural density and moisture

3. Importance of soil classification

4. Description of soils in logs

D. Summary

Study reference: Earth Manual, pages 158-170

FIELD INVESTIGATIONS - CANALS AND MISCELLANEOUS STRUCTURES - FOUNDATIONS AND MATERIALS

A. Introduction - Importance of Investigations

B. Planning Investigations

1. Review tentative plans for structures.

2. Review potential soil problems - early recognition.

3. Review local conditions, features, and performance of similar construction.

4. Review previous investigation reports.

5. Degree of exploration varies with stage of investigation.

   a. Investigate most serious problems first.

   b. Use methods appropriate to furnishing the desired information.

6. Maps - Topography, geology and soil conditions, hydrology.

C. Stages of Investigation

1. Reconnaissance - Descriptive

   a. Properties based on visual classification

   b. General appraisal and evaluation of subsurface

2. Feasibility - Qualitative

   a. Limited exploration - properties determined by index tests.

3. Specifications - Quantitative and specific

   a. Engineering properties determined for various soil types.

   b. Sufficient exploration to establish conditions at all critical points.

4. Characteristics of subsurface developed in progressively greater detail as work proceeds.

D. Soil Components, Properties, and Characteristics

1. Boulders and cobbles - stable, occurrence in situ improves stability, angularity increases stability.

2. Gravel and sand - easy to compact, little affected by moisture, not subject to frost action. Well graded less pervious and more stable than poorly graded.

3. Silt - unstable with increase of moisture, tendency to become quick. Relatively impervious, difficult to compact, highly susceptible to frost heave, easily erodible, subject to piping.

4. Clay - cohesive strength increases with decrease in moisture. Low permeability, difficult to compact when wet, subject to expansion and shrinkage.

5. Organic matter - undesirable.

E. Engineering Use Chart - Relative desirability of typical soils for engineering purposes.

1. Compacted earth canal lining - impervious, erosion resistant, stable. Relative desirability - GW-GC, GC, SW-SC, SC, SC-CL, CL, GM.

2. Structure backfill - desirability dependent upon backfill requirements.

a. Impervious backfill impervious gravelly soils, SW-SC, SC, CL, SC-CL, SM-SC, SC-ML, etc.

b. Pervious backfill -

GW, GP, SW, SP <5 percent fines
GW-GM, GW-GC, GP-GM, GP-GC <8 percent fines
SW-SC and SM, require special consideration, suitability dependent on gradation and plasticity.

F. Surface Exploration - Familiarity with geologic landforms, soils associated with them, and potential problems.

1. Glacial areas

a. Heterogeneous - any type of soil, in almost any form, and in any proportion.

b. Hydraulic structures - sutiable design precautions required.

c. Light structures - no difficulty.

d. Heavy structures - differential settlement.

2. Loessial areas

a. Settlement upon wetting

b. Piping

c. Recompaction - reliable platform for footings

d. Vertical slopes

3. Sand-dune areas

a. Transmission towers - seeding or road oil.

b. Piles to depth unaffected by any shifting of dunes.

c. Runoff very low.

d. Canals lined.

G. Subsurface Exploration - Identify soils in foundation, their extent (dimensions), and properties.

1. Point structures (small buildings, towers) - a single hole will often be sufficient.

2. Powerplants and pumping stations - special attention

a. Vibrations and sensitivity to settlement.

b. Detailed and thorough. Holes at plant corners, turbine locations, heavy bearing walls. Supplemented with additional borings.

3. Switchyards - settlement and uplift

4. Line structures (canals, laterals, drains, etc.)

   a. Spacing of holes dependent on subsurface.

   b. Canals - feasibility, 1-mile intervals
      - specifications, 2,000-foot intervals

   c. Minimum - 10 feet below invert grade, greater depths for questionable soils.

5. Borrow areas for canals - required excavation, adjacent borrow, distant borrow.

H. Exploration for Materials with Specific Properties

1. Usually not feasible to obtain material with ideal characteristics.

2. Volume substituted for quality; special processing may be more economical than longer hauls.

3. Impervious materials - blending of coarse material with impervious soil; erosion resistant and impervious.

I. Structure performance is dependent on investigation and information which is performed and provided.

Study assignment: Earth Manual, Chapter II

FIELD PERMEABILITY TEST (WELL PERMEAMETER METHOD)

A. Purpose is to obtain the permeability characteristics of the soil in place, particularly for the estimation of canal seepage.

B. The Well Permeameter Test consists of the measurement of the rate of water outflow (under constant head) from an uncased well augered in the soil to be tested.

C. The Detailed Test Procedure is presented in Designation E-19 (pages 546-562) of the Earth Manual.

D. The major precautions to be taken in conduction of the well permeameter test are:

1. Determine by exploration to a level about three times the well water depth the classification of the canal soils and location of the ground-water surface.

2. Avoid unnecessary disturbance (particularly compaction) of soil on the well sides and bottom.

3. Use clean sand for backfilling wells.

4. Use clean water for permeability test.

5. Continue test sufficiently long to reach an approximate steady state flow condition.

E. Canal Seepage Estimates

1. To compute seepage from an unlined canal based on well permeameter tests, use the following formula:

$$S = \frac{k(B + 2d)}{365CW_p}$$

where

S = seepage in cubic feet per square foot per day

k = coefficient of permeability in feet per year from the well permeameter test

B = canal water surface width in feet

d = canal water depth in feet

W_p = canal wetted perimeter in feet

C = seepage factor determined from well-permeameter and ponding tests. C = 1 for wind-deposited soils (dune sand and loess) and C = 3.5 for water-deposited soils.

F. The Shallow-well-type Field Permeability Test is for use in canal earth linings for construction control and evaluation purposes.

Study references: Earth Manual, Designations E-19 and E-36

FIELD INVESTIGATIONS - SAMPLING FOUNDATIONS

A. Introduction

B. Hand Methods

1. Apparatus
2. Methods

C. Mechanical Drilling Methods

1. Apparatus
2. Procedure - General
3. Drilling fluids
4. Denison-type sampler
5. Pitcher sampler
6. Thin-wall drive sampler
7. Piston sampler
8. Double-tube auger sampler
9. Core sampler
10. Full-flo core barrel
11. Triple-tube core barrel
12. Field measurements and records

D. Shipment Precautions and Instructions

Study reference: Earth Manual, Designation E-2

FIELD INVESTIGATIONS - EARTH DAM FOUNDATIONS

A. Introduction

B. Purpose of Investigations

1. To determine foundation stability
2. To determine foundation permeability
3. To facilitate estimate of foundation treatment
4. To avoid pitfalls during construction and operation

C. Stages of Investigations

1. Office investigations
   a. Review of previous investigations and report
   b. Aerial photographs
   c. Drill logs
2. Field investigations
   a. Reconnaissance (descriptive)
   b. Feasibility (qualitative)
   c. Specifications (quantitative, specific)

D. Problem Areas

1. Overburden
   a. Stability
      (1) Landslides
      (2) Compressible soils
      (3) Weak soils (low shear strength or low cohesion)

b. Permeability

(1) Grain size and gradation

(2) Physical state and type

c. Miscellaneous

2. Rock

a. Stability

(1) Thickness and dip of beds

(2) Unstable seams and inter-beds

(3) Faults

(4) Weathering

b. Permeability

(1) Cavities

(2) Joints and fractures

(3) Soluble rocks

(4) Weathering

c. Miscellaneous

E. Design Features that Overcome Foundation Defects

1. Areas of instability

a. Excavation

b. Consolidation

c. Embankment design

d. Filters

e. Drains and pressure-relief wells

2. Areas of excessive permeability

   a. Excavation

   b. Grout curtain

   c. Cutoff walls

   d. Blankets

   e. Drains and pressure-relief wells

F. Case History

Study reference: Earth Manual, Chapter II

FIELD INVESTIGATIONS - EARTH DAM MATERIALS

A. Why Earth Dam Materials Investigation?

1. Inventory of materials

   a. Locate deposits

   b. Identify deposits

   c. Determine quantity

   d. Significant features of occurrence

   e. Properties of soils

B. Investigation by Stages

1. Reconnaissance stage

   a. Descriptive data

   b. Investigate large area

   c. Visual classification

   d. Advantages and disadvantages

2. Feasibility stage

   a. Confirm and revise previous investigation

   b. Inventory

   c. Some exploration

   d. Describe material sources

   e. Estimate quantities

   f. Physical tests

   g. Recommendations for use

3. Specifications stage

   a. Review all previous work

   b. Extensive exploration

   c. Assure adequate material

   d. Specific and quantitative data

   e. Sample selection

   f. Detailed report

4. Construction stage

   a. Distribution of material in borrow area

   b. Moisture conditions

   c. Depth of cuts

   d. Material distribution in embankment

C. Design Considerations

1. Permeability

2. Stability

3. Shrinkage and compression

4. Piping and washing out of fines

5. Economical utilization

D. Construction Considerations

1. Accessibility

2. Natural moisture

3. Workability

E. Rock Material

1. Use of rock material

2. Riprap requirements

   a. Sound, dense, durable, angular, equidimensional, reasonably well graded

3. Investigation

   a. Similar use

   b. Joint spacing

   c. Economical production

   d. Blast test

F. Planning

1. Office

   a. Topographic maps

   b. Geologic maps

   c. Agriculture soil maps

   d. Aerial photos

2. Field

   a. Aid of geologist

   b. Surface indications

   c. Subsurface exploration

   d. Inspection test pits

   e. In-place moisture and density

G. Reports

1. Reconnaissance. - Letter or preliminary geologic report.

2. Feasibility. - Feasibility materials report.

3. Specifications. - Specifications design data materials report (Earth Manual, page 175).

4. Construction. - Periodic construction report (L-29), materials distribution chart.

INVENTORY carefully all construction materials to be considered as borrow areas.

plus

REPORT clearly and fully the significant features of occurrence and soil properties.

equals

ECONOMICAL and ADEQUATE design.

Study reference: Earth Manual, Chapter II

ROCK MECHANICS - IN SITU TESTING

A. Introduction

1. Reasons for presenting subject to Earth Control and Investigation Course participants.

2. Reasons for conducting tests (basic type information we wish to obtain).

3. Projects where in situ tests have been conducted.

B. Types of Tests

1. Uniaxial deformation - explanation

   a. Slides

   b. Display flat jack

2. Radial jacking - explanation

   a. Slides

   b. Display flat jack

3. Direct shear - explanation

   a. Slides

4. Plate gouge - explanation

   a. Slides

C. Summary

D. Conclusions

E. Questions and allow students to examine displays.

ROCK MECHANICS - FIELD INSTRUMENTATION - PART I

A. Shotcrete Instrumentation at Hunter Tunnel

1. Hunter Tunnel - Purpose and Description
2. Shotcrete characteristics
3. Instrumentation
   a. description
   b. installation
   c. data recording
4. Results
5. Conclusions
6. Displays

B. Overcore Stress Relief Method

1. Instrumentation
   a. Description
   b. Test procedures
2. Examples of field test programs
   a. Tests in rock
   b. Tests in concrete dams
3. Conclusions
4. Displays

ROCK MECHANICS - FIELD INSTRUMENTATION - PART II

A. Introduction

1. Reasons for instrumentation

a. Stability and safety

b. Performance of supports

B. Types of instrumentation

1. Extensometers

a. Multiple position

(1) Slides

(2) Application

b. Single Position

(1) Slides

(2) Application

c. Model displays

2. Meters

a. Joint

(1) Slides

(2) Application

(3) Model dispaly

3. Hydraulic pressure cell

a. Use with rock bolts

b. Model display

C. Summary

D. Conclusions

E. Questions and examination of displays

7-1750 (3-71)
Bureau of Reclamation

CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg, that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
Inches	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters
Feet	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	*929.03	Square centimeters
Square feet	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	*0.40469	Hectares
Acres	*4,046.9	Square meters
Acres	*0.0040469	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	*946.358	Cubic centimeters
Quarts (U.S.)	*0.946331	Liters
Gallons (U.S.)	*3,785.43	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	*0.00378543	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54590	Liters
Cubic feet	28.3160	Liters
Cubic yards	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters
Acre-feet	*1,233,500	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
Short tons (2,000 lb)	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
Pounds per square inch	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Pounds per square foot	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
Pounds per cubic foot	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
Inch-pounds	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
Foot-pounds	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
Feet per second	0.3048 (exactly)*	Meters per second
Feet per year	$*0.965873 \times 10^{-6}$	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	*0.3048	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	*0.028317	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	*0.453592	Kilograms
Pounds	*4.4482	Newtons
Pounds	$*4.4482 \times 10^5$	Dynes

Table II—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories
British thermal units (Btu)	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	*1.35582	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	*1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	*0.09290	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	*304.8	Liters per square meter per day
Pound-seconds per square foot (viscosity)	*4.8824	Kilogram second per square meter
Square feet per second (viscosity)	*0.092903	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	*35.3147	Millicuries per cubic meter
Millilamps per square foot	*10.7639	Millilamps per square meter
Gallons per square yard	*4.527219	Liters per square meter
Pounds per inch	*0.17858	Kilograms per centimeter

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Grouting (BW)
C. E. Tackett, Civil Engineer
Regions PN (Part), MP (Part),
Tunnels (BW)
J. Dill, Civil Engineer
Regions SW (Part), MP (Part),
Pipe (BW)

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CONTRACT SECTION NO.
J. W. Pepple

CONTRACT SECTION NO.
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DRAWING TRANSMITTAL SEC
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  - CONTRACT SECTION NO. 3
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