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Stabilization Studies on Soil-Cement Mixtures for Experimental Lining--Logan Experimental Section--Logan, Utah

United States Department of the Interior, Bureau of Reclamation

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STABILIZATION STUDIES ON SOIL-CEMENT MIXTURES FOR EXPERIMENTAL LINING--LOGAN EXPERIMENTAL SECTION--LOGAN, UTAH
(Supplement to EM-170)
Earth Materials Laboratory Report No. EM-198

RESEARCH AND GEOLOGY DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO
MARCH 10, 1949
CONTENTS

Introduction .................................................. 1
Summary ...................................................... 1
Discussion of Laboratory Tests ......................... 2
Recommendations ........................................... 4

APPENDIX

Test Procedures ........................................... 5
Gradation Curves ........................................ 1
Compaction Curves ...................................... 2
Durability Curves ....................................... 3 and 4
Soil-cement Specimens .................................. 1, 2, and 3
INTRODUCTION

Earth Materials Laboratory Report No. EM-170 covers the laboratory tests made on one type of soil from Logan, Utah, for the purpose of using the soil in soil-cement canal lining experiments. The intention was that two types of soil would be used for experimental linings at Logan, Utah: a fine sandy soil, poorly graded with little or no silt (Classification Symbol SP) and a fine sandy soil with excess silt (Classification Symbol SF-silty). These field test sections which will provide durability and permeability information gathered under natural conditions were carried out as part of a joint lower-cost canal lining experiment by the Utah Agricultural Experiment Station, the Soil Conservation Service, and the Bureau of Reclamation. When Report EM-170 was written (April 19, 1948) only materials of the "SF-silty" type were available for testing. This material was identified as Laboratory Sample No. 11H-24. A second shipment of samples on June 11, 1948, included a material of the SP type (Laboratory Sample No. 11H-X65) and laboratory tests were begun on this material. Before the tests were completed it was necessary to install the linings with the two types of soil. The installation of these linings as well as additional linings of bituminous materials was made during the period August 16 to 21, 1948, and reported in the Research and Geology Field Trip Report No. 476 by L. M. Ellisperman and V. S. Meissner. Several field samples of the test installations were transmitted to the Denver laboratory for testing. This supplemental report covers the laboratory tests on the SP material and on the field samples.

SUMMARY

The laboratory tests reported herein indicate that a standard soil-cement mixture of the SP material containing 15-percent cement by volume (4.05 sacks of cement per cubic yard), compacted to maximum density at optimum moisture content should produce a suitable canal lining. The recommendation which was made on the basis of inspection and incomplete test data before the laboratory tests were completed for the installation of the test lining, specified that 14.82-percent cement by volume be used (4 sacks per cubic yard). Analysis of the field samples shows that this material was placed at an average of 16.1-percent cement by volume or 4.35 sacks per cubic yard.
Analysis of field samples also showed that the SF-silty material (11H-24) contained an average of 11.60-percent cement by volume (3.13 sacks per cubic yard). The amount of cement recommended in EM-170 for this soil was 12.0 percent by volume or 3.24 sacks per cubic yard.

The durability tests made on the field samples indicate that all the soil-cement mixtures should provide satisfactory canal linings based on the current soil-cement criteria.

DISCUSSION OF LABORATORY TESTS

The gradation curves for the two materials used in the test installations are shown on Figure 1. The laboratory tests and results for Sample 11H-24, the SF-silty material (sand with excess silt), are contained in EM-170. Sample 11H-X65 is classified SP (sand, poorly graded) by the modified Casagrande classification. The moisture limits tests (liquid limit = 22 and plasticity index = 0) and the mechanical analysis place this material in Group A-3 according to the Public Roads Administration classification. Previous tests on soil-cement mixtures showed that a soil of this type could be stabilized with 6- to 12-percent cement by volume. With this information tests were undertaken to determine the amount of cement necessary to stabilize the soil. A list of the tests conducted is included in the Appendix. Before the tests were completed it was necessary to make recommendations on the field installation of this material. These recommendations are included in the table, page 5.

Standard laboratory compaction tests were made on the natural soil and on soil-cement mixtures containing approximately 6- and 12-percent cement by volume. The compaction curves are shown on Figure 2 in the Appendix, and the following table shows the variation in maximum density and optimum moisture due to the change in cement content:

<table>
<thead>
<tr>
<th>Cement content by volume (percent)</th>
<th>Maximum dry density (pcf)</th>
<th>Optimum moisture content (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100.1</td>
<td>16.0</td>
</tr>
<tr>
<td>6.34</td>
<td>105.8</td>
<td>14.8</td>
</tr>
<tr>
<td>13.11</td>
<td>109.3</td>
<td>13.5</td>
</tr>
</tbody>
</table>

The compaction curves, Figure 2, show that the maximum density increases and the optimum moisture content decreases with increasing cement content.

The quantities of soil, cement, and water required to produce specimens for the durability tests containing 8-, 10-, 12-, and 14-percent cement by volume when compacted to maximum density at optimum moisture were calculated by interpolation from the compaction data. Two types of specimens are required for the durability tests. One, called the volume and moisture change specimen, is used to determine the volume and moisture...
changes which occur during either the wet-dry or freeze-thaw test. The other specimen, called the soil-cement loss specimen, is vigorously brushed after each cycle of either the wet-dry or the freeze-thaw test to remove the loosened material from the specimen. Four soil-cement loss specimens, containing 8-, 10-, 12-, and 14-percent cement by volume, and one volume and moisture change specimen containing 12 percent by volume, were molded for use in the wet-dry test. A similar set of specimens were molded for use in the freeze-thaw test. The data from the tests provide information for determining the volume changes, the moisture changes, and the soil-cement losses. The information compiled during the tests on these soil-cement mixtures is contained in the following table:

**STABILITY TEST DATA**

(ILL-X65)

<table>
<thead>
<tr>
<th>Standard Soil-cement Mixtures</th>
</tr>
</thead>
</table>
| by volume: of soil :density: content :content : moisture :change :loss
| (percent):(percent):(pcf):(percent):(percent):(percent):(percent)
| Wetting-and-Drying Test |
| 11.88 : 11.58 : 107.7 : 13.4 : 13.7 : 20.8 : -0.4 : 22.2 |
| Freezing-and-Thawing Test |
| 11.87 : 11.58 : 107.6 : 13.8 : 14.1 : 21.6 : +0.3 : 11.4 |

Figure 3, Appendix, illustrates graphically the relation between cement content by volume and the soil-cement losses after 12 cycles of both the wet-dry and the freeze-thaw tests for the standard soil-cement mixture. Photograph 1 shows the soil-cement specimens after 12 cycles of wetting-and-drying and Photograph 2 shows the specimens after 12 cycles of freezing-and-thawing.

The following criteria have been established for the selection of cement contents necessary to produce soil-cement in the laboratory of satisfactory hardness, durability, and serviceability:

a. Soil-cement losses during 12 cycles of either the wet-dry or the freeze-thaw test shall not exceed 14 percent for soil of the Public Roads Administration Soil Groups A-2 and A-3.

b. The maximum volume at any time during either the wet-dry or the freeze-thaw test shall not exceed the volume at the time of molding by more than 2 percent.
c. The maximum moisture content during either the wet-dry or the freeze-thaw test shall not exceed that quantity which will completely fill the voids of the specimen at the time of molding.

d. For soils containing less than 35-percent silt and clay, the cement content recommended for field installations shall be 2 percent higher than the amount necessary to produce satisfactory soil-cement in the laboratory.

The wetting-and-drying test provided the most severe condition for the soil-cement mixtures of Sample 11H-X65. Figure 3 shows that 13-percent cement by volume would satisfy criterion (a). The volume and moisture change criteria (b) and (c) are satisfied by the same soil-cement mixture.

Permeability tests on soil-cement specimens containing 6- and 12-percent cement by volume were made. The permeability rate of the 6-percent mixture is 19.8 feet per year and of the 12-percent mixture is 1.1 feet per year. The natural material placed at maximum density has a rate of 356 feet per year.

The field samples taken during the test installations were subjected to the standard freeze-thaw and wet-dry tests. The cement content of these specimens was determined in accordance with the ASTM Method D606-44T. The results of these tests are plotted on Figures 3 and 4. The field soil-cement specimens of "SP" material, similar to 11H-X65, contained 16.1-percent cement by volume and suffered a 3.0-percent soil-cement loss in the wet-dry test and a 6.1-percent soil-cement loss in the freeze-thaw test. The field soil-cement specimens of "SP-silty" material, similar to 11H-24, contained 11.6-percent cement by volume and suffered a 7.6-percent soil-cement loss in the wet-dry test and a 5.0-percent soil-cement loss in the freeze-thaw test. Photograph 3 shows the field specimens after 12 cycles of the standard tests.

RECOMMENDATIONS

In compliance with criterion (d) the cement requirement for the 11H-X65 material is 15 percent by volume. The following table includes the recommended cement contents and other pertinent information for both types of soils used in the test installations as well as the conditions achieved in the field.
### STANDARD SOIL-CEMENT MIXTURES

<table>
<thead>
<tr>
<th></th>
<th>Laboratory Sample</th>
<th>Laboratory Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No 11H-24</td>
<td>No 11H X-65</td>
</tr>
<tr>
<td></td>
<td>Recommended</td>
<td>Achieved</td>
</tr>
<tr>
<td>Maximum dry density, soil plus cement-pcf</td>
<td>115.0</td>
<td>113.0</td>
</tr>
<tr>
<td>Moisture content, by dry weight of soil plus cement-percent</td>
<td>11.6</td>
<td>12.1</td>
</tr>
<tr>
<td>Cement content, by volume-percent</td>
<td>12.0</td>
<td>11.60</td>
</tr>
<tr>
<td>Cement content by weight of dry soil-percent</td>
<td>10.88</td>
<td>10.70</td>
</tr>
<tr>
<td>Cement, soil, water proportion by weight</td>
<td>1:9.2:1.18</td>
<td>1:9.37:1.28</td>
</tr>
<tr>
<td>Cement, sacks per cubic yard in place</td>
<td>3.24</td>
<td>3.13</td>
</tr>
</tbody>
</table>
**TEST PROCEDURES**

**Standard properties tests.** The standard properties tests are performed in accordance with the procedure outlined in the Bureau of Reclamation publication, *Laboratory Procedure in Testing Earth Material for Foundation and Construction Purposes*, dated July 21, 1946. The detailed procedures are given in the following pages of the publication:

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Analysis</td>
<td>40</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>57</td>
</tr>
<tr>
<td>Compaction Test</td>
<td>68</td>
</tr>
<tr>
<td>Percolation Test</td>
<td>75</td>
</tr>
</tbody>
</table>

**Durability tests.** The durability and other pertinent tests are performed in accordance with the following ASTM procedures:

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Method of Test for Liquid Limit of Soils--ASTM</td>
<td>D 423-39</td>
</tr>
<tr>
<td>Standard Method of Test for Plastic Limit and Plasticity Index of Soils--ASTM</td>
<td>D 424-39</td>
</tr>
<tr>
<td>Standard Method of Wetting and Drying Test of Compacted Soil-cement Mixtures--ASTM</td>
<td>D 559-44</td>
</tr>
<tr>
<td>Standard Method of Freezing and Thawing Test of Compacted Soil-cement Mixtures--ASTM</td>
<td>D 560-44</td>
</tr>
<tr>
<td>Test for Cement Content of Soil-cement Mixtures (tentative)</td>
<td>D 806-44T</td>
</tr>
</tbody>
</table>
HYDROMETER ANALYSIS

TIME READINGS

U.S. STANDARD SERIES

SIEVE ANALYSIS

CLEAR SQUARE OPENINGS

DIA. OF PARTICLE IN MILLIMETERS

CLAY (PLASTIC) TO SILT (NON-PLASTIC)

SAND

GRAVEL

COBBLES

NOTES:

II H - 24 SF - Silty

II H - X 65 SP

FIGURE 1

U.S. STANDARD SERIES

PERCENT PASSING

PERCENT RETAINED

DIAMETER OF PARTICLE IN MILLIMETERS

COARSE FINE MEDIAN COARSE FINE COARSE COBBLES
MOISTURE-PENETRATION RESISTANCE CURVE

MOISTURE-PERCENT OF DRY WEIGHT

THEORETICAL CURVE AT COMPLETE SATURATION (NUMERALS INDICATE PERCENTAGE OF TOTAL VOLUME OCCUPIED BY WATER i.e. % voids)

% Cement

5%

5%

2%

SOIL PROPERTIES

SPECIFIC GRAVITY

S P

SOIL CLASSIFICATION

% LARGER THEN TESTED

MAX DRY DENSITY (PCF)

OPT MOISTURE (%)

Ben Res. at Opt. Moist. (PSI)

COMPACTION TEST CURVES

LOGAN UTAH

EXPERIMENTAL

SOIL-CEMENT CANAL LINING

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

X-D-930

Figure No. 2
SOIL-CEMENT LOSS - PERCENT

CEMENT BY VOLUME - PERCENT

Freeze-Thaw test

Wet-Dry test

Recommended

14 % Allowable

Field sample

11Hx65 STANDARD
SOIL-CEMENT SPECIMENS

SOIL-CEMENT LOSSES
LOGAN UTAH
EXPERIMENTAL
SOIL-CEMENT CANAL LINING

X-0-2668

X-0-2668

X-0-2668

X-0-2668
Standard Mixture - 11H-X65 after 12 cycles of wetting and drying. Volume and moisture change specimen: No. 11 at 12% cement content by volume. Brushed soil-cement loss specimens: No. 12 at 8%; No. 13 at 10%; No. 14 at 12%; and No. 15 at 14% cement content by volume.
Standard Mixture - 11H-X65 after 12 cycles of freezing and thawing. Volume and moisture change specimen: No. 16 at 12% cement content by volume.

Brushed soil-cement loss specimens: No. 17 at 8%; No. 18 at 10%; No. 19 at 12%; and No. 20 at 14% cement content by volume.
Freezing - and - Thawing
21. "SP" Soil
22. "SF-silty" Soil
23. "SP" Soil

Wetting - and - Drying
24. "SF-silty" Soil
25. "SP" Soil
26. "SF-silty" Soil

Field Samples