GR-84-14

USE OF THE HARVARD MINIATURE APPARATUS FOR OBTAINING MOISTURE-UNIT WEIGHT RELATIONSHIPS OF SOILS

September 1984
Engineering and Research Center

U. S. Department of the Interior
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16. ABSTRACT

A study was performed to investigate the use of the Harvard miniature apparatus as a potentially viable means for obtaining moisture-unit weight relationships of soils. A literature search was performed along with a series of pilot tests on representative soil samples to compare the results obtained from the Harvard miniature apparatus with those from the USBR Proctor compaction test procedure. The use of the Harvard miniature apparatus is recommended for obtaining moisture-unit weight relationships under certain conditions for two reasons: (1) it saves time and (2) less material is required to perform the test.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. *DESCRIPTORS*-- *Harvard miniature apparatus/ *Proctor compaction test/moisture-unit weight relationship/ construction control/ soil compaction/ dry density/ optimum moisture content/ Proctor curves/ compaction/ compaction tests/ *compaction equipment/ field tests/ laboratory tests

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by

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Geotechnical Branch
Division of Research and Laboratory Services
Engineering and Research Center
Denver, Colorado

SI METRIC

September 1984

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

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INTRODUCTION

Optimum moisture content and maximum dry unit weight are two important criteria for evaluating the state of compactness for most cohesive soil masses whether they are deposited naturally or placed by man. The "Proctor Compaction Test (Moisture-Density Relations of Soils)," USBR (Bureau of Reclamation) Designation E-11 [1]*, is performed in all USBR soil laboratories, both at the E&R Center (Engineering and Research Center) and in the field. Two disadvantages of the currently used test method are (1) the amount of material required to complete the test – approximately 25 to 50 lbm (11.4 to 22.7 kg), depending on the type of material being evaluated; and (2) the length of time required to perform the test.

This report is intended to introduce a new test procedure, "USBR 5510, Performing Laboratory Compaction of Soils – Harvard Miniature" and present the results of a search of the literature comparing the results obtained from standard Proctor compaction with those obtained from the Harvard miniature apparatus.

COMPACTION TEST METHODS

The compaction test was originally developed as a basis for controlling compaction in the field. It was intended as a tool to obtain a maximum unit weight that would aid in construction control; i.e., improved settlement characteristics and strength. However, some engineers have erroneously come to accept "maximum unit weight" and "optimum moisture content" as fixed values irrespective of the soil type or compactive effort.

The traditional standard Proctor compaction test requires that the soil specimen be compacted in 3 layers, with 25 blows per layer, in a mold having a volume of 1/30 ft^3 (944 cm^3). The compactive effort is achieved by dropping a 5.5-lbm (2.5 kg) rammer from a height of 12 in (30.5 cm). The standard USBR procedure also requires that the soil specimen be compacted in 3 layers, with 25 blows per layer. However, the standard USBR test uses a mold having a volume of 1/20 ft^3 (1416 cm^3), and the compactive effort is achieved by using a 5.5-lbm (2.5 kg) rammer dropped from a height of 18 in (45.7 cm).

Both techniques impart the same compactive effort, 12,375 ft-lbf/ft^3 (5.925×10^5 N·m/m^3), to the soil specimen. A moisture-unit weight plot is obtained when a series of soil specimens are

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* Numbers in brackets refer to entries in the bibliography.

compacted at predetermined moisture contents using either the USBR procedure or the standard Proctor compaction test. The corresponding dry unit weight at each moisture content is determined, and a moisture-unit weight plot is obtained.

Recently, the Harvard miniature compaction apparatus, introduced by Wilson in 1950 [2], has been used by researchers for preparing triaxial specimens [2, 3] and by others to obtain moisture-unit weight relationships of soils [2, 4]. The use of this device results in a quick moisture-unit weight determination and requires only 4 to 6 lbm (1.8 to 2.7 kg) of material. The current USBR test procedure for compacting soil specimens using the Harvard miniature compaction apparatus is presented in the appendix. This procedure was adapted from the method suggested by Wilson in 1970 [4] and from the experience of USBR personnel.

In 1962, the Highway Research Board studied a number of factors that could influence compaction test results [5]. The report concentrated on three principal types of compaction efforts currently used: impact type, kneading type, and the vibratory type. In addition to the different types of compaction efforts, the Highway Research Board report also cited other variations that influence the moisture-unit weight relationships of soils:

- Size of mold
- Amount of compactive effort
- Maximum size aggregate permitted
- Method of supporting the mold
- Method of preparing the soil for testing

COMPARISON OF HARVARD MINIATURE WITH PROCTOR COMPACTION

In 1950, Wilson [2] compared field compaction characteristics that had been studied extensively by the Waterways Experiment Station [6] with the results obtained using the Harvard miniature compaction apparatus. Figure 1 shows the results obtained from compacting a clayey sand and a silty clay. Figure 1 shows that it is possible to obtain moisture-unit weight curves that closely duplicate field compaction curves by selecting suitable spring force, number of layers, and tamps per layer. The test results obtained by Wilson also indicate that no standard procedure can successfully duplicate field compaction curves for all soil types.

Similar compaction tests were performed at the E&R Center geotechnical laboratories. The USBR compaction procedure (Designation E-11) and Harvard miniature compaction tests were per-

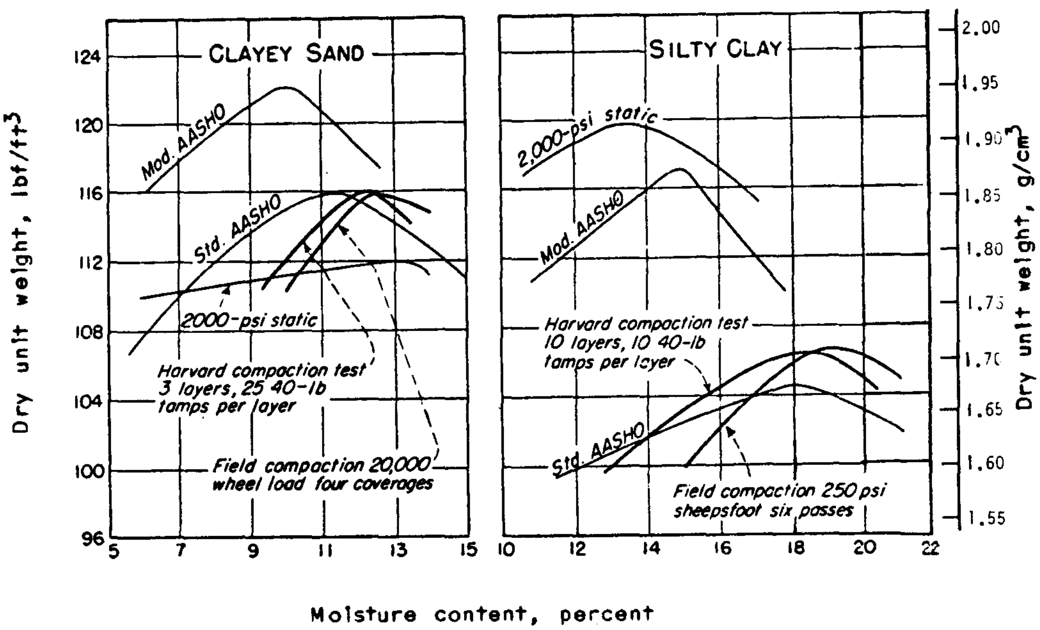


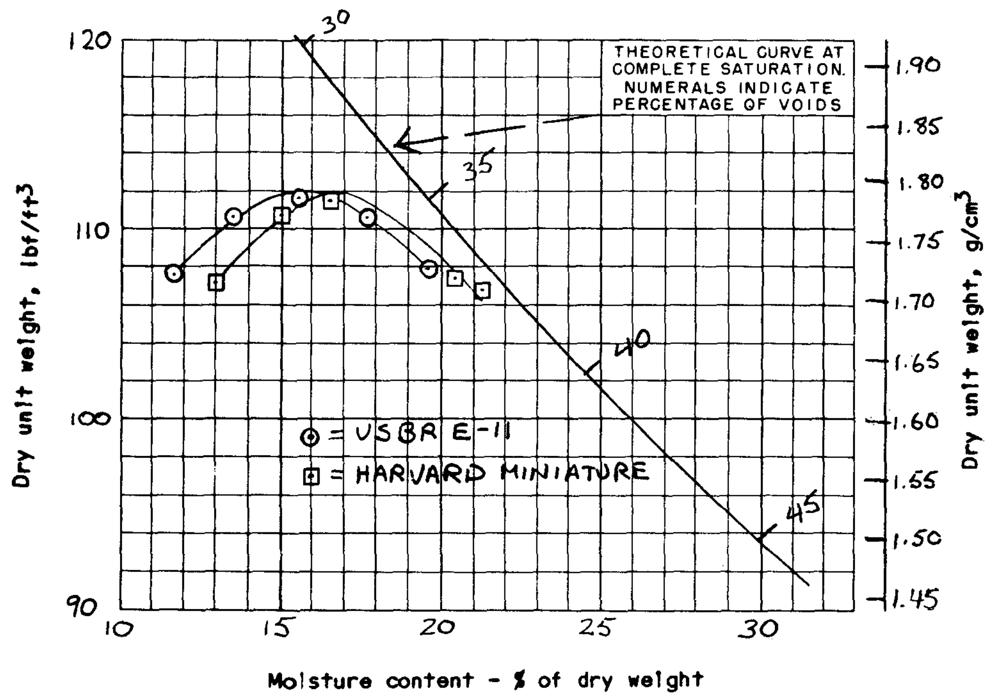
Figure 1. – Field and laboratory results compared for various methods of obtaining moisture-unit weight curves.

formed on a number of soil types. Harvard miniature compaction tests were performed by applying 25 tamps with a 20-lbf (89-N) spring force to each of the 5 lifts in the Harvard miniature mold (see appendix A for a detailed description of the testing procedure). Results of the compaction tests are shown on figure 2.

The Harvard miniature compaction test resulted in optimum moisture contents that were 1.1 to 1.8 percent greater than those obtained from the USBR compaction method. Maximum dry unit weights from the Harvard miniature compaction ranged from 0.4 to 3.3 lbf/ft^3 (6.4 to 52.8 kg/m^3) lower than maximum dry unit weights obtained from the USBR compaction method.

CONCLUSIONS

Use of the Harvard miniature compaction apparatus produces moisture-unit weight curves in less time than the Proctor compaction test and requires only a fraction of the material. Comparative results indicate that the Harvard miniature method can be used to match standard compaction values when the spring force, the number of layers, and the number of tamps per layer are adjusted according to the soil type. Because time and materials could be saved by using the Harvard miniature apparatus instead of the standard Proctor device, similar investigations should be conducted on a variety of soil types to develop a data base, from which laboratory and field personnel can draw, to ensure quality moisture-unit weight determinations.



COMPACTION - PENETRATION RESISTANCE CURVES

CLASSIFICATION SYMBOL SC

GRADATION SUMMARY

GRAVEL	%
SAND	62 %
FINES	38 %

ATTERBERG LIMITS

LIQUID LIMIT	29 %
PLASTICITY INDEX	10
SHRINKAGE LIMIT	%

SPECIFIC GRAVITY

MINUS NO. 4	2.73
PLUS NO. 4	
BULK	
APPARENT	
ABSORPTION	%

COMPACTION

% LARGER THAN TESTED 0

MAX. DRY UNIT WEIGHT 111.6 lb/ft^3 (1.788 kg/cm^2)

OPTIMUM MOISTURE CONT. 15.5 %

PENETRATION RESISTANCE 900 lbf/in^2 (63.3 kg/cm^2)

NOTES: UNIT #6

Harvard miniature

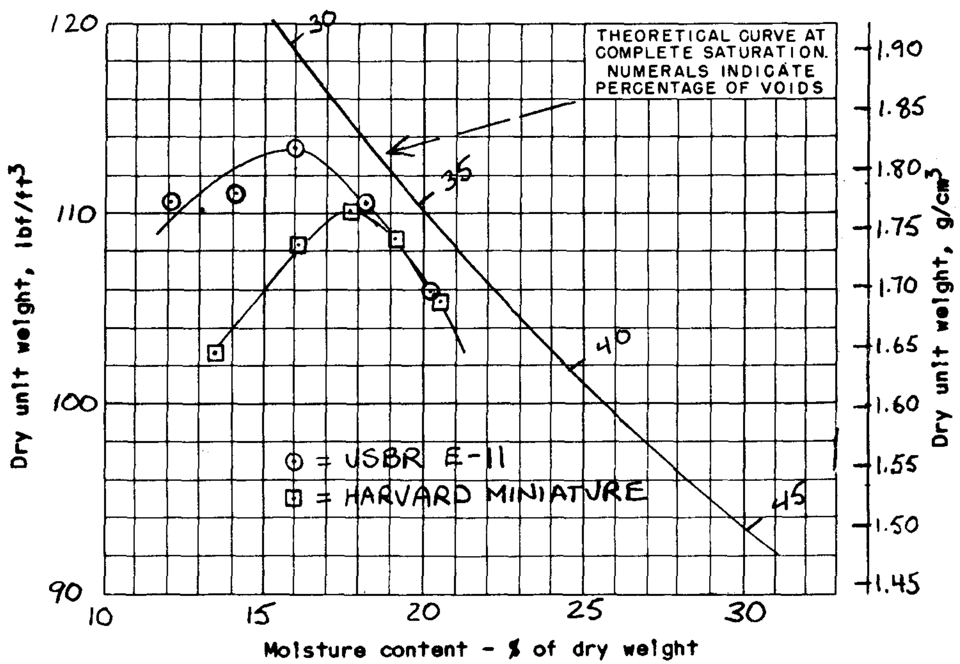
25 blows @ 20 lbf

for each 5 lifts

γ_{max} = 111.5 lb/ft^3

W_{OPT} = 16.6 %

Figure 2. – Harvard miniature vs. USBR E-11 compaction test results (sheet 1 of 3).



COMPACTION - PENETRATION RESISTANCE CURVES

CLASSIFICATION SYMBOL SM-SC

GRADATION SUMMARY

- GRAVEL 2 %
- SAND 50 %
- FINES 48 %

ATTERBERG LIMITS

- LIQUID LIMIT 26 %
- PLASTICITY INDEX 6
- SHRINKAGE LIMIT ____ %

SPECIFIC GRAVITY

- MINUS NO. 4 2.72
- PLUS NO. 4 ____
- BULK ____
- APPARENT ____
- ABSORPTION ____ %

COMPACTION (USBR)

- % LARGER THAN TESTED ____
- MAX. DRY UNIT WEIGHT 113.4 lb/ft³ (1.816 kg/cm²)
- OPTIMUM MOISTURE CONT. 16 %
- PENETRATION RESISTANCE 1000 lbf/in² (70.3 kg/cm²)

NOTES: UNIT #3

Harvard miniature

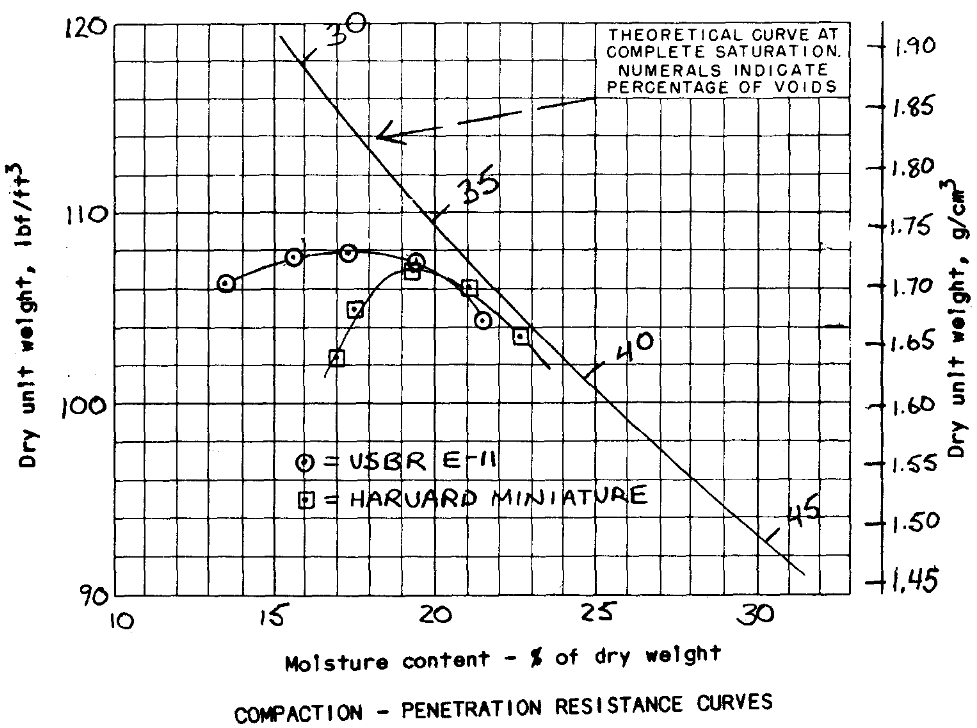
25 blows @ 20 lbf

for each 5 lifts

γ_D MAX = 110 lb/ft³

W_{OPT} = 18%

Figure 2. – Harvard miniature vs. USBR E-11 compaction test results (sheet 2 of 3).



CLASSIFICATION SYMBOL CL

GRADATION SUMMARY
- GRAVEL — %
- SAND 44 %
- FINES 56 %

ATTERBERG LIMITS
- LIQUID LIMIT 39 %
- PLASTICITY INDEX 22
- SHRINKAGE LIMIT ____ %

SPECIFIC GRAVITY
- MINUS NO. 4 2.70
- PLUS NO. 4
- BULK ____
- APPARENT ____
- ABSORPTION ____ %

COMPACTION
- % LARGER THAN TESTED ____
- MAX. DRY UNIT WEIGHT 107.9 lb/ft³ (1.728 kg/cm²)
- OPTIMUM MOISTURE CONT. 17.5 %
- PENETRATION RESISTANCE ____ lbf/in² (____ kg/cm²)

NOTES:

Harvard miniature
25 blows @ 20 lbf
for each 5 lifts
γ_D max = 107.0 lb/ft³
W opt = 19.3%

Figure 2. – Harvard miniature vs. USBR E-11 compaction test results (sheet 3 of 3).

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APPENDIX

PROCEDURE FOR PERFORMING LABORATORY COMPACTION OF SOILS – HARVARD MINIATURE

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 5510-84A

PROCEDURE FOR

PERFORMING LABORATORY COMPACTION OF SOILS - HARVARD MINIATURE

INTRODUCTION

This test procedure is under the jurisdiction of the Geotechnical Branch, code D-1540, Division of Research and Laboratory Services, Engineering and Research Center, Denver, Colorado. The test procedure is issued under the fixed designation USBR 5510. The number immediately following the designation indicates the year of acceptance or the year of last revision.

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1. Scope

1.1 This designation outlines the procedure for performing laboratory compaction of soils using the Harvard miniature compaction apparatus.

1.2 The test procedure is used to determine the relationship between the moisture content of the portion of soil passing the No. 4 sieve and the corresponding dry unit weight when the soil is compacted using the Harvard miniature compaction apparatus.

2. Auxiliary Tests

2.1 A representative soil sample must be obtained in accordance with USBR 5205 prior to performing this test procedure. The moisture content must be determined in accordance with USBR 5300 as part of performing this test procedure. The specific gravity of the soil sample must be determined in accordance with USBR 5320 in order to plot the zero air voids curve on the compaction plot.

3. Applicable Documents

3.1 USBR Test Designations:

USBR 1009, Calibrating Compaction Molds
USBR 1012, Calibrating Balances or Scales
USBR 1020, Calibrating Ovens
USBR 1025, Calibrating Sieves and Screens
USBR 3900, Standard Definitions of Terms and Symbols Relating to Soil Mechanics
USBR 5000, Determining Unified Soil Classification (Laboratory Method)
USBR 5005, Determining Unified Soil Classification (Visual Method)
USBR 5205, Preparing Representative Soil Samples for Laboratory Use
USBR 5300, Determining Moisture Content of Soils by the Oven Method
USBR 5320, Determining Specific Gravity of Soils

3.2 ASTM Standard:

E 11, Specification for Wire-Cloth Sieves for Testing Purposes[1]

4. Summary of Method

4.1 A soil specimen is placed and compacted in a mold in five lifts using a special tamping device. Twenty-five tamps are applied to each lift to achieve a standard compactive effort. To establish a compaction curve, at least five soil specimens are compacted; each at a different moisture content. Moisture-unit weight points both wet and dry of optimum moisture content are required.

5. Significance and Use

5.1 The Harvard miniature compaction test is performed to obtain data to develop a soil moisture-unit weight compaction curve.

5.2 The compaction mold has a volume equal to 1/454 ft^3. The mass of the soil filling the mold (in grams) is therefore numerically equal to the unit weight of the soil in pounds force per cubic foot.

5.3 The test equipment and procedures were developed to compact soil in the laboratory using a kneading action which simulates the action of a sheepsfoot roller.

5.4 This test procedure can be used in place of the standard compaction test when a limited amount of material is available. The test procedure also requires less time to perform than the standard compaction test.

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1 Annual Book of ASTM Standards, vols. 04.01, 04.02, or 14.02.

6. Terminology

6.1 All definitions are in accordance with USBR 3900. Terms of particular significance are listed here:

6.1.1 Compaction curve (moisture-unit weight relationship). - The curve showing the relationship between the dry unit weight and the moisture content of a soil for a given compactive effort

6.1.2 Optimum moisture content. - The moisture content at which a soil can be compacted to the maximum dry unit weight by a given compactive effort

6.1.3 Maximum unit weight. - The dry unit weight defined by the peak of a compaction curve

6.1.4 Zero air voids curve. - The curve showing the relationship between dry unit weights and corresponding moisture contents, assuming the voids are completely filled with water

7. Apparatus

7.1 General apparatus. -

7.1.1 Drying oven. - An oven, thermostatically controlled, preferably of the forced-draft type, and capable of maintaining a uniform temperature of 230 ± 9 °F (110 ± 5 °C) throughout the drying chamber.

7.1.2 Balance or scale. - Portable platform or platform counter, 100-pound capacity, readable to 0.5 pound, and accurate to 0.5 percent over the full range.

7.1.3 Blance or scale. - Portable platform or platform counter, 1000-gram capacity, readable to 0.1 gram, and accurate to 0.1 percent over the full range.

7.1.4 Straightedge. - A stiff metal straightedge of any convenient length. The scraping edge must have a straightness tolerance of ± 0.005 inch (± 0.13 mm) and must be beveled if it is thicker than 1/8 inch (3 mm).

7.1.5 Sieve. - No. 4 sieve (4.75 mm), conforming to the requirements of ASTM: E 11.

7.1.6 Bags. - 1-quart, moisture-proof, plastic.

7.2 Equipment unique to this procedure (see fig. 1). -

7.2.1 Specimen ejector. - To facilitate removal of the soil sample from the mold

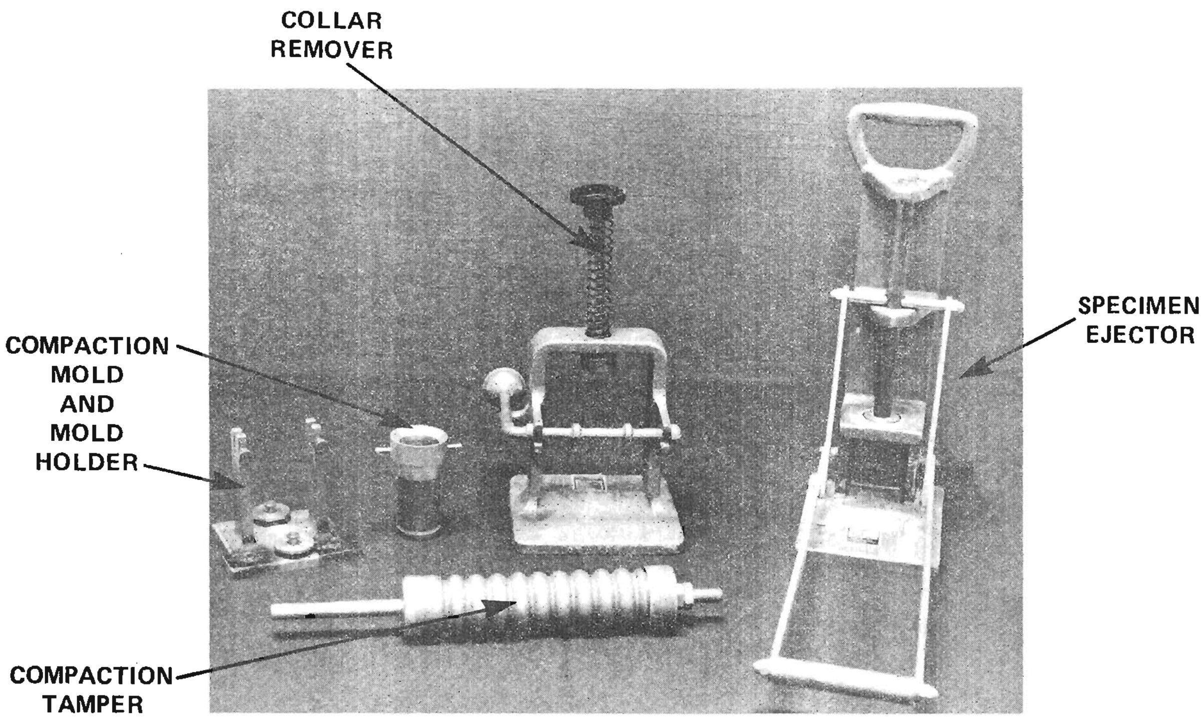


Figure 1. – Harvard miniature compaction test equipment.

7.2.2 Mold holder. - A clamping device to hold the mold and collar in place during compaction, with solid baseplate

7.2.3 Compaction mold. - 1/454-ft^3 capacity with detachable extension collar

7.2.4 Collar remover. - A device for holding the compacted soil and mold in place while the extension collar is being removed

7.2.5 Compaction tamper. - Provided with springs which can be preset for a 20-lbf loading

7.3 Miscellaneous equipment. - Mixing pans, spoon, trowel, spatula, etc., for thoroughly mixing the soil sample with water; a wood plunger for leveling compaction lifts

8. Reagents and Materials

8.1 Tapwater that is free of acids, alkalies, or oils and is generally suitable for drinking should be used for wetting the soil prior to compaction.

9. Precautions

9.1 Safety precautions. -

9.1.1 The surface on which the test is to be performed must be strong enough to support the compactive effort.

9.2 Technical precautions. -

9.2.1 The test specimen should be prepared and compacted as quickly as possible to minimize unrecorded moisture loss.

10. Sampling, Test Specimens, and Test Units

10.1 Sample preparation. -

10.1.1 Prepare a representative soil sample in accordance with USBR 5205.

10.2 Specimen preparation. -

10.2.1 Air-dry 4 to 6 pounds (1800 to 2700 kg) of the representative soil sample.

NOTE 1. - If 4 to 6 pounds (1800 to 2700 kg) of material are not available, carefully plan the number of specimens and corresponding moisture contents to avoid reusing material.

10.2.2 After drying, thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of the particles.

10.2.3 Pass the material through a No. 4 sieve and mix thoroughly.

10.2.4 Split this material into six representative portions such that each portion contains enough material for two specimens (or one specimen if not enough material is available, see note 1).

10.2.5 Prepare a series of five specimens by adding increasing amounts of water to five of the portions prepared in accordance with subparagraph 10.2.4. The moisture contents selected are to be such that at least two specimens wet of optimum moisture and at least two specimens dry of optimum moisture are obtained. The moisture contents selected should normally vary by approximately 1-1/2 to 2 percent. One portion should be kept at the air-dried moisture content in case an additional specimen is needed.

10.2.6 Optimum moisture content is estimated for a given soil type by experience or can be done by using the following values (from ref. 2):

Soil classification group USBR 5000 or 5005	Maximum dry unit weight (kN/m^3)	(lbf/ft^3)	Optimum moisture contents (%)
SM	17.9 ± .2	114 ± 1	14.5 ± 0.4
SM-SC	18.7 ± .2	119 ± 1	12.8 ± 0.5
SC	18.1 ± .2	115 ± 1	14.7 ± 0.4
ML	16.2 ± .2	103 ± 1	19.2 ± 0.7
ML-CL	17.1 ± .3	109 ± 2	16.8 ± 0.7
CL	17.0 ± .2	108 ± 1	17.3 ± 0.3
MH	12.9 ± .6	82 ± 4	36.3 ± 3.2
CH	14.8 ± .3	94 ± 2	25.5 ± 1.2

The ± entry indicates 90-percent confidence limits of the average value.

10.2.7 Determine the amount of water to be added to each portion as prepared in subparagraph 10.2.4 in accordance with the procedure outlined in appendix X1.

10.2.8 Thoroughly mix the material for each specimen to ensure an even distribution of moisture throughout.

10.2.9 Place each portion in a plastic moisture-proof bag and store in accordance with the following standing times:

Classification USBR 5000 or 5005	Minimum standing time (hours)
SM	3
ML, CL, OL, SC	18
MH, CH, OH, PT	36

10.2.10 In normal situations, it is important that material from a compacted specimen not be remixed and reused. If, due to lack of material, this must be done, it must be noted in the report.

11. Calibration and Standardization

11.1 Check to see that the equipment is currently calibrated in accordance with the applicable calibration procedure. If the calibration is not current, perform the calibration before using the equipment for this test procedure.

USBR 1009, Calibrating Compacton Molds
USBR 1012, Calibrating Balances or Scales
USBR 1020, Calibrating Ovens
USBR 1025, Calibrating Sieves and Screens

11.2 Compaction tamper calibration. -

11.2.1 Determine the mass of the compaction tamper to the nearest 0.5 pound using the 100-pound capacity scale.

NOTE 2. - It is convenient to use a tare equal to the mass of the compaction tamper so that the resulting mass in pounds is numerically equal to the compactive effort of the tamper.

11.2.2 Place the compaction tamper on the center of the scale holding it around the barrel using both hands.

11.2.3 Push down on the barrel until it just loses contact with the two calibration nuts that are located at the top of the compaction tamper.

11.2.4 Read the scale when the tamper is in the position as described in subparagraph 11.2.3.

11.2.5 The desired compaction load is 20 pounds force. Adjust the calibration nuts as necessary to obtain the appropriate scale reading. If the observed scale reading is too low, the calibration nuts need to be moved down; if the scale reading is too high, the calibration nuts need to be moved up.

11.2.6 Record the final scale as the compaction calibration on the Harvard Miniature Compaction Test form as shown on figure 2.

12. Conditioning

12.1 Place the material for each soil specimen as prepared in subparagraph 10.2 in a moisture-proof plastic bag and store them in accordance with the minimum standing times outlined in subparagraph 10.2.9.

13. Procedure

13.1 All data are to be recorded on the Harvard Miniature Compaction Test form as shown on figure 2.

13.2 Determine the mass of the empty compaction mold to the nearest 0.1 gram and, record the value on the Harvard Miniature Compaction Test form.

13.3 Pass the material to be compacted through a No. 4 sieve to break up any lumps of soil resulting from the specimen preparation procedure.

13.4 Each test specimen must be compacted as follows:

NOTE 3. - The compaction mold and tamper must be clean, dry, and free of any lubricants.

13.4.1 Securely clamp the mold and collar to the base.

13.4.2 Place the desired amount of loose soil in the mold.

NOTE 4. - Two to three slightly heaping teaspoons are generally required for each layer.

13.4.3 Level the surface by pressing down lightly with a wood plunger.

13.4.4 Insert the tamper in the mold until it is in contact with the soil surface.

13.4.5 Press down firmly until the spring is compressed to the full calibrated load (20 pounds force).

13.4.6 Release the force and shift the tamper to a new position.

13.4.7 Each of the first four tamps should be applied in separate quadrants and adjacent to the mold. The fifth tamp should be in the center, making one complete coverage.

13.4.8 Repeat the cycle outlined in subparagraph 13.4.7 until 25 tamps have been applied. The tamps should be applied at the approximate rate of one tamp per second.

13.4.9 It is important to slightly offset the location of the tamps during the compaction effort to ensure complete and even coverage of the specimen surface.

13.4.10 Repeat subparagraphs 13.4.2 through 13.4.9 until five layers have been placed.

Harvard Miniature Compaction Test

Test designation USBR 5510-84A

Project EM Feature Example Sample No. 1

Tested by B.S. Computed by B.S. Checked by D.C.

Date 14 FEB 84 Blows per layer 25 No. of layers 5

Compaction calibration 20.0 lb Volume of mold 62.4 cm³

Specimen No.	1	2	3	4	5	6	7
Wet unit weight determinations							
Desired moisture content (%)	14.0	16.0	18.0	20.0	22.0		
Water added (g) or (mL) or (cm^3)	18.5	27.4	36.6	43.5	52.5		
Mass of mold + wet soil (g)	239.9	249.1	252.9	252.8	250.4		
Mass of mold (g)	123.4	123.4	123.4	123.4	123.4		
Mass of wet soil (g)	116.5	125.7	129.5	129.4	127.0		
Wet unit weight (kN/m^3)	18.3	19.8	20.4	20.3	20.0		
Moisture content determinations							
Dish No.	L-39	L-31	L-27	50	204		
Mass of dish + wet soil (g)	234.6	252.7	261.1	299.8	297.0		
Mass of dish + dry soil (g)	220.8	235.3	241.7	279.0	275.4		
Mass of dish (g)	118.3	127.2	132.1	170.7	170.1		
Mass of water (g)	13.8	17.4	19.4	20.8	21.6		
Mass of dry soil (g)	102.5	108.1	109.6	108.3	105.3		
Moisture content (% of dry mass)	13.5	16.1	17.7	19.2	20.5		
Dry unit weight determinations							
Dry unit weight (kN/m^3)*	16.1	17.0	17.3	17.1	16.6		

Comments:

Auxiliary tests:

USBR 5205-84
USBR 5300-84
USBR 5320-84

Figure 2. – Example data on the Harvard miniature compaction test form.

13.4.11 The top layer should extend at least 1/2 inch, but not more than 3/4 inch, into the extension collar. If, after the last layer is compacted, the specimen is too short or too long, it should be discarded and a new specimen placed.

13.4.12 Transfer the mold assembly to the collar remover and release the collar clamps.

13.4.13 Press down firmly on the piston and at the same time pull up on the handle prying the collar loose from the compacted soil.

13.4.14 Remove the mold from the base and, using the straightedge, carefully trim away any excess soil from the top and bottom of the mold.

13.4.15 Determine the mass of the mold and the compacted soil to the nearest 0.1 gram and record the value.

13.4.16 Remove the specimen from the mold using the sample ejector.

13.4.17 Place the specimen in a suitable container for drying and determination of moisture content.

13.5 Compact the additional specimens from material as prepared in paragraph 10, repeating the procedures outlined in subparagraphs 13.3 and 13.4, until at least five points have been established.

13.6 Determine the moisture content of each compacted specimen in accordance with USBR 5300.

13.7 Calculate the wet and dry unit weights for each compacted specimen.

13.8 Plot the moisture contents and corresponding dry unit weights as shown on figure 3.

13.9 If the plotted points do not fall on both sides of the optimum moisture content, additional specimens must be prepared and compacted at appropriate moisture contents.

13.10 If additional material is not available, see subparagraph 10.2.10.

13.11 Determine the specific gravity for the soil sample in accordance with USBR 5320.

13.12 Use table X2, Points for Curve of Complete Saturation (zero air voids curve), to obtain appropriate dry density and corresponding moisture content values assuming the voids are completely filled with water.

13.13 Plot the zero air voids curve as shown on figure 3 and outlined in appendix X2.

14. Calculations

14.1 Calculate the moisture content using the following expression:

$$w = \left(\frac{A - B}{B - C}\right) \times 100 \qquad (1)$$

where:

w = Percentage of moisture in the specimen
A = Mass of dish and wet soil (g)
B = Mass of dish and dried soil (g)
C = Mass of dish (g)
100 = Constant to convert to percent

14.2 Calculate the wet unit of the compacted soil specimen as follows:

$$\gamma\ wet = \left(\frac{A - C}{V}\right) \times 9.8067 \qquad (2)$$

where:

γ wet = Wet unit weight of compacted soil (kN/m^3)
V = Volume of mold (cm^3)
9.8067 = Constant to convert from g/cm^3 to kN/m^3 (see note 5)

NOTE 5. - Three constants are combined into one in this calculation. Density in g/cm^3 is multiplied by 1000 to convert to kg/m^3; that number is multiplied by the acceleration of gravity, g ($9.8067\ m/s^2$), to convert to unit weight in N/m^3.

14.3 Calculate the dry unit weight of the soil specimen as follows:

$$\gamma_d = \left(\frac{\gamma\ wet}{w + 100}\right) \times 100 \qquad (3)$$

where:

γ_d = Dry unit weight of compacted soil (kN/m^3)

15. Report

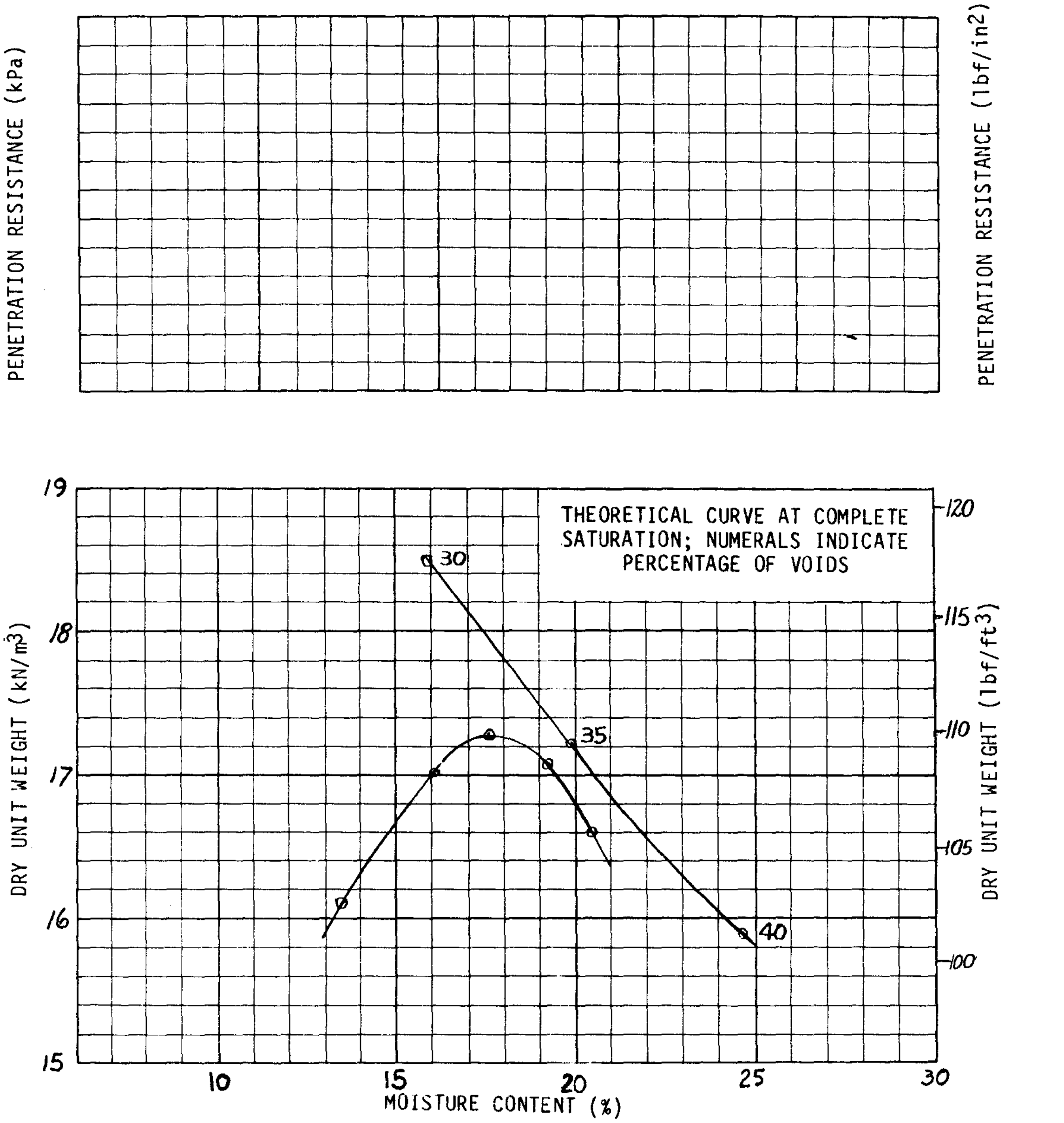
15.1 The report is to consist of the following USBR forms:

15.1.1 Harvard Miniature Compaction Test form, figure 2

15.1.2 Compaction-Penetration Resistance Curves (Moisture-Unit Weight plot), figure 3

15.1.3 Added Water Determination for Compaction Test Specimens, figure X1.1

COMPACTION - PENETRATION RESISTANCE CURVES



CLASSIFICATION CL

GRAVEL 0 %
SAND 35 %
FINES 65 %

ATTERBERG LIMITS

LIQUID LIMIT 32 %
PLASTICITY INDEX 20 %
SHRINKAGE LIMIT ___ %

SPECIFIC GRAVITY

MINUS NO. 4 2.70
PLUS NO. 4 ___
BULK ___
APPARENT ___
ABSORPTION ___ %

COMPACTION

METHOD Harvard miniature
PERCENT LARGER THAN TESTED 0
MAXIMUM DRY UNIT WEIGHT 17.3 kN/m^3
OPTIMUM MOISTURE CONTENT 17.7 %
DEGREE OF SATURATION ___ %
PENETRATION RESISTANCE ___ kPa

NOTES ___

SAMPLE NO. 1 HOLE NO. ___ DEPTH ___ ft

Figure 3. – Compaction-Penetration resistance curves.

15.2 See appendix X3 for blank data sheets.

REFERENCES

[1] "Suggested Method of Test for Moisture-Density Relations of Soils Using Harvard Compacton Apparatus," Special Procedures for Testing Soil and Rock for Engineering Purposes, ASTM Special Publication 479, Philadelphia, Pennsylvania, June 1970.

[2] Design of Small Dams, 2d edition, U.S. Department of the Interior, Bureau of Reclamation, Water Resources Technical Publication, U.S. Government Printing Office, Washington, D.C., revised reprint 1977.

APPENDIX X1

Added Water Determination for Compaction Test Specimens

X1.1 Scope

X1.1.1 This appendix outlines the procedure for determining the amount of water to be added to test specimens in order to achieve the desired moisture contents.

X1.2 Procedure

X1.2.1 All data are to be recorded on the Added Water Determination for Compaction Test Specimens form, as shown on figure X1.1. A blank data sheet in included in appendix X3.

X1.2.2 The air-dried moisture content of the soil specimens is to be predetermined in accordance with USBR 5300. Record the moisture content value in column (1) on the form as the "initial moisture content (%)."

X1.2.3 The desired moisture content for each specimen is predetermined. Record the values in column (2) on the form as the "desired moisture content (%)."

X1.2.4 Calculate the moisture content difference for each test specimen using the following expression:

$$(3) = (2) - (1)$$

where:

(3) = Moisture content difference (%)
(2) = Desired moisture content (%)
(1) = Initial moisture content (%)

Record the values for each test specimen in column (3) of the form as "moisture content (%) difference."

X1.2.5 Determine the mass of each soil specimen and container. Record the value in column (4) of the form as "mass of specimen and container."

X1.2.6 Determine the mass of the container and record the value in column (5) of the form as "mass of container."

X1.2.7 Calculate the mass of the specimen using the following expression:

$$(6) = (4) - (5)$$

ADDED WATER DETERMINATION
FOR COMPACTION TEST SPECIMENS

Test designation USBR 5510 - 84

Project E.M. Feature Example Sample No. 1

Computed by B.S. Date 3 JAN 84 Checked by D.C. Date Jan 4, 84

Specimen	Moisture content (%)			Mass (g)				
	Initial (1)	Desired (2)	Difference (3)	Specimen and container (4)	Container (5)	Specimen (6)	Dry mass of specimen (7)	Water to add (8)
1	9.5	14.0	4.5	673.7	223.7	450.0	411.0	18.5
2	9.5	16.0	6.5	686.0	223.7	462.3	422.2	27.4
3	9.5	18.0	8.5	695.5	223.7	471.8	430.9	36.6
4	9.5	20.0	10.5	677.3	223.7	453.6	414.2	43.5
5	9.5	22.0	12.5	683.7	223.7	460.0	420.1	52.5
			$(2) - (1)$			$(4) - (5)$	$\frac{(6)}{[100 + (1)]} \times 100$	$(7) \times \frac{(3)}{100}$

Comments: For Harvard Miniature Compaction Test Specimen wet-up

Auxiliary Tests: USBR 5300-84

Figure X1.1. – Added water determination for compaction test specimens.

where:

(6) = Mass of specimen (g)
(4) = Mass of specimen and container (g)
(5) = Mass of container (g)

Record the value in column (6) of the form as "mass of specimen."

NOTE X1.1. - If a container is not needed, subparagraphs X1.2.5 through X1.2.7 may be omitted and the mass of the specimen recorded directly.

X1.2.8 Calculate the dry mass of the specimen using the following expression:

$$(7) = \frac{(6)}{[100 + (1)]} \times 100$$

where:

(7) = Dry mass of specimen (g)
(6) = Mass of specimen (g)
(1) = Initial moisture content (%)

Record the value in column (7) of the form as "dry mass of specimen."

X1.2.9 Calculate the mass of water to add to each soil specimen using the following expression:

$$(8) = (7) \times \frac{(3)}{100}$$

where:

(8) = Mass of water to add (g)
(7) = Dry of specimen (g)
(3) = Moisture content difference (%)

Record the value in column (8) of the form as "mass of water to add."

NOTE X1.2. - The water may be measured by volume, rather than mass. For the purpose of this procedure, consider 1 g = 1 mL = 1 cm^3.

APPENDIX X2

Zero Air Voids Curve Determination (Curve of Complete Saturation)

X2.1 Scope

X2.1.1 This appendix outlines the procedure for obtaining and plotting appropriate dry unit weight and corresponding moisture content values given the specific gravity of the soil, along with a completed moisture-unit weight plot.

X2.2 Procedure

X2.2.1 Predetermine the specific gravity of the soil specimen in accordance with USBR 5320.

X2.2.2 Obtain a completed moisture-unit weight plot for the soil from a compaction test.

X2.2.3 Use table X2, Points for Curve of Complete Saturation, to obtain appropriate moisture-unit weight points for a given specific gravity.

X2.2.4 Enter the table with the appropriate specific gravity.

X2.2.5 Multiply the dry unit weight values given by 0.15709 to obtain kN/m^3.

X2.2.6 Select at least three values of dry unit weights and corresponding moisture contents that approximately bracket the maximum and minimum dry unit weight values obtained in the compaction test.

X2.2.7 Plot the points selected as shown on figure 3. The points are to be labeles with the corresponding percentage of void values also found in table X2.

NOTE X2.1. - The values found in table X2 may be calculated using the following relationships:

$$\gamma_d = \gamma_w G_s \; 1 - \frac{n}{100}$$

$$w = \frac{n \gamma_w}{\gamma_d}$$

where:

γ_d = Dry unit weight of soil ($lbf/ft3$ or kN/m^3)
γ_w = Unit weight of water, in units identical to those used with γ_d
G_s = Specific gravity of the soil
n = Porosity (%)
w = Water content (%)

Table X2. – Points for curve of complete saturation (sheet 1 of 3).

Percent voids / Specific gravity	10	15	20	25	30	35	40	45	50	55	60
	Dry unit weight in pounds force per cubic foot Moisture content in percent										
2.45	137.6	130.0	122.4	114.8	107.1	99.5	91.8	84.2	76.5	68.8	61.2
	4.5	7.2	10.2	13.6	17.5	22.0	27.2	33.4	40.8	49.9	61.3
2.46	138.3	130.6	122.8	115.2	107.5	99.8	92.2	84.6	76.8	69.2	61.5
	4.5	7.2	10.2	13.5	17.4	21.9	27.1	33.2	40.7	49.6	60.9
2.47	138.9	131.2	123.5	115.7	108.0	100.4	92.6	84.9	77.2	69.4	61.7
	4.5	7.1	10.1	13.5	17.3	21.8	27.0	33.1	40.5	49.5	60.7
2.48	139.5	131.6	124.0	116.2	108.5	100.7	93.0	85.2	77.5	69.7	62.0
	4.5	7.1	10.1	13.4	17.3	21.7	26.9	33.0	40.3	49.3	60.4
2.49	140.0	132.2	124.4	116.6	108.9	101.1	93.3	85.6	77.8	70.0	62.2
	4.5	7.1	10.1	13.4	17.2	21.6	26.8	32.8	40.2	49.2	60.3
2.50	140.4	132.6	124.8	117.0	109.2	101.4	93.6	85.9	78.1	70.2	62.4
	4.4	7.1	10.0	13.3	17.1	21.5	26.7	32.7	40.0	48.9	60.0
2.51	141.0	133.2	125.4	117.5	109.7	101.9	94.1	86.3	78.2	70.6	62.7
	4.4	7.0	10.0	13.3	17.1	21.4	26.5	32.6	39.9	48.7	59.8
2.52	141.6	133.8	125.9	118.1	110.2	102.4	94.4	86.6	78.7	70.8	63.0
	4.4	7.0	9.9	13.2	17.0	21.4	26.5	32.4	39.7	48.5	59.5
2.53	142.2	134.4	126.3	118.5	110.5	102.7	94.7	86.9	79.0	71.2	63.2
	4.4	7.0	9.9	13.2	16.9	21.3	26.3	32.3	39.5	48.3	59.3
2.54	142.8	134.9	126.9	119.0	111.1	103.1	95.2	87.2	79.3	71.4	63.4
	4.4	6.9	9.9	13.1	16.8	21.2	26.2	32.2	39.4	48.1	59.1
2.55	143.2	135.3	127.3	119.4	111.4	103.4	95.5	87.5	79.6	71.6	63.6
	4.4	6.9	9.8	13.1	16.8	21.1	26.2	32.1	39.2	47.9	58.9
2.56	143.8	135.8	127.8	119.8	111.8	103.8	95.8	87.9	79.9	71.9	63.9
	4.3	6.9	9.8	13.0	16.8	21.1	26.1	32.0	39.1	47.7	58.6
2.57	144.3	136.3	128.3	120.3	112.3	104.2	96.2	88.2	80.2	72.2	64.1
	4.3	6.9	9.7	13.0	16.7	21.0	26.0	31.8	38.9	47.5	58.4
2.58	144.9	136.8	128.8	120.7	112.7	104.6	96.6	88.5	80.5	72.4	64.4
	4.3	6.8	9.7	12.9	16.7	20.9	25.9	31.7	38.8	47.4	58.1
2.59	145.5	137.4	129.3	121.2	113.1	105.1	97.0	88.9	80.8	72.7	64.6
	4.3	6.8	9.7	12.9	16.6	20.8	25.6	31.6	38.6	47.2	57.9

Table X2. – Points for curve of complete saturation (sheet 2 of 3).

Percent voids	10	15	20	25	30	35	40	45	50	55	60
Specific gravity	Dry unit weight in pounds force per cubic foot Moisture content in percent										
2.60	146.0	137.9	129.8	121.7	113.6	105.5	97.3	89.2	81.1	73.0	64.9
	4.3	6.8	9.6	12.9	16.5	20.7	25.7	31.5	38.5	47.0	57.7
2.61	146.6	138.4	130.3	122.2	114.0	105.9	97.7	89.6	81.4	73.3	65.1
	4.3	6.7	9.6	12.8	16.4	20.6	25.6	31.3	38.3	46.8	57.5
2.62	147.2	138.9	130.8	122.6	114.5	106.3	98.1	89.9	81.8	73.6	65.4
	4.2	6.7	9.6	12.7	16.4	20.6	25.5	31.2	38.2	46.6	57.3
2.63	147.7	139.5	131.3	123.1	114.9	106.7	98.5	90.3	82.1	73.8	65.6
	4.2	6.7	9.5	12.7	16.3	20.5	25.4	31.1	38.0	46.5	57.1
2.64	148.3	140.0	131.8	123.6	115.3	107.1	98.9	90.6	82.4	74.1	65.9
	4.2	6.7	9.5	12.6	16.3	20.4	25.3	31.0	37.9	46.3	56.8
2.65	148.8	140.6	132.3	124.0	115.8	107.5	99.2	91.0	82.7	74.4	66.1
	4.2	6.6	9.4	12.6	16.2	20.3	25.2	30.8	37.7	46.1	56.6
2.66	149.4	141.1	132.8	124.5	116.2	107.9	99.6	91.3	83.0	74.7	66.4
	4.2	6.6	9.4	12.5	16.1	20.3	25.1	30.8	37.6	45.9	56.4
2.67	150.0	141.6	133.3	125.0	116.6	108.3	100.0	91.6	83.3	75.0	66.6
	4.2	6.6	9.4	12.5	16.1	20.2	25.0	30.7	37.5	45.7	56.2
2.68	150.5	142.2	133.8	125.4	117.1	108.7	100.3	92.0	83.6	75.3	66.9
	4.1	6.6	9.3	12.4	16.0	20.1	24.9	30.5	37.3	45.6	56.0
2.69	151.1	142.7	134.3	125.9	117.5	109.1	100.7	92.3	83.9	75.5	67.1
	4.1	6.6	9.3	12.4	16.0	20.0	24.8	30.4	37.2	45.5	55.8
2.70	151.6	143.2	134.8	126.4	117.9	109.5	101.1	92.7	84.2	75.8	67.4
	4.1	6.5	9.3	12.3	15.9	19.9	24.7	30.3	37.0	45.3	55.6
2.71	152.2	143.7	135.3	126.8	118.4	109.9	101.5	93.0	84.6	76.1	67.6
	4.1	6.5	9.2	12.3	15.8	19.9	24.6	30.2	36.9	45.1	55.4
2.72	152.8	144.3	135.8	127.3	118.8	110.3	101.8	93.4	84.9	76.4	67.9
	4.1	6.5	9.2	12.3	15.8	19.8	24.6	30.1	36.8	44.9	55.2
2.73	153.3	144.8	136.3	127.8	119.3	110.7	102.2	93.7	85.2	76.7	68.1
	4.1	6.4	9.2	12.2	15.7	19.7	24.4	29.9	36.6	44.7	55.0
2.74	153.9	145.3	136.8	128.2	119.7	111.1	102.6	94.0	85.5	76.9	68.4
	4.1	6.4	9.1	12.2	15.7	19.7	24.4	29.9	36.5	44.6	54.8
2.75	154.4	145.9	137.3	128.7	120.1	111.5	103.0	94.4	85.8	77.2	68.6
	4.0	6.4	9.1	12.1	15.6	19.6	24.3	29.8	36.4	44.4	54.6
2.76	155.0	146.5	137.8	129.1	120.6	111.9	103.3	94.7	86.2	77.5	68.9
	4.0	6.4	9.1	12.1	15.7	19.5	24.2	29.7	36.2	44.3	54.4
2.77	155.6	147.0	138.3	129.6	121.0	112.4	103.7	95.1	86.5	77.8	69.2
	4.0	6.4	9.0	12.0	15.5	19.4	24.0	29.5	36.2	44.2	54.2
2.78	156.1	147.5	138.8	130.1	121.4	112.8	104.1	95.4	86.8	78.1	69.4
	4.0	6.4	9.0	12.0	15.4	19.4	23.9	29.4	36.0	44.0	54.0
2.79	156.8	148.1	139.3	130.6	121.9	113.2	104.5	95.8	87.1	78.4	69.7
	4.0	6.3	9.0	12.0	15.3	19.3	23.8	29.3	35.9	43.8	53.8

Table X2. – Points for curve of complete saturation (sheet 3 of 3).

	Percent voids										
Percent voids	10	15	20	25	30	35	40	45	50	55	60
Specific gravity	Dry unit weight in pounds force per cubic foot Moisture content in percent										
2.80	157.4	148.6	139.8	131.0	122.3	113.6	104.8	96.1	87.5	78.7	70.0
	4.0	6.3	8.9	11.9	15.3	19.2	23.8	29.2	35.7	43.6	53.5
2.81	157.8	149.0	140.0	131.5	122.7	114.0	105.2	96.4	87.7	78.9	70.1
	4.0	6.3	8.9	11.9	15.2	19.2	23.7	29.1	35.6	43.4	53.4
2.82	158.4	149.6	140.8	132.0	123.2	114.4	105.6	96.8	88.0	79.2	70.4
	3.9	6.3	8.9	11.8	15.2	19.1	23.6	29.0	35.5	43.3	53.2
2.83	159.0	150.2	141.3	132.4	123.6	114.8	106.0	97.1	88.3	79.5	70.7
	3.9	6.2	8.8	11.8	15.1	19.0	23.6	28.9	35.3	43.2	53.0
2.84	159.6	150.7	141.8	132.9	124.1	115.2	106.3	97.5	88.7	79.8	70.9
	3.9	6.2	8.8	11.7	15.1	18.9	23.5	28.8	35.2	43.0	52.8
2.85	160.1	151.2	142.2	133.4	124.5	115.6	106.7	97.9	89.0	80.1	71.2
	3.9	6.2	8.8	11.7	15.0	18.9	23.4	28.7	35.1	42.9	52.6
2.86	160.7	151.8	142.8	134.9	124.9	116.0	107.1	98.2	89.3	80.3	71.4
	3.9	6.2	8.7	11.6	15.0	18.8	23.3	28.6	35.0	42.8	52.5
2.87	160.1	151.2	143.3	134.3	125.4	116.4	107.5	98.5	89.6	80.7	71.7
	3.9	6.2	8.7	11.6	14.9	18.8	23.2	28.5	34.8	42.5	52.3
2.88	161.8	152.8	143.8	134.8	125.8	116.8	107.8	98.8	89.9	80.9	71.9
	3.9	6.1	8.7	11.6	14.9	18.7	23.2	28.4	34.7	42.4	52.1
2.89	162.4	153.4	144.2	135.2	126.2	117.2	108.2	99.2	90.2	81.2	72.2
	3.8	6.1	8.7	11.5	14.8	18.6	23.0	28.3	34.6	42.3	51.9
2.90	162.9	153.9	144.8	135.7	126.7	117.6	108.6	99.5	90.5	81.5	72.4
	3.8	6.1	8.6	11.5	14.8	18.6	23.0	28.2	34.5	42.1	51.7

BLANK DATA SHEETS

Harvard Miniature Compaction Test

Test designation USBR 5510-__ __

Project______________ Feature______________ Sample No.______________

Tested by______________ Computed by______________ Checked by______________

Date______________ Blows per layer______________ No. of layers______________

Compaction calibration______________ Volume of mold______________ cm^3

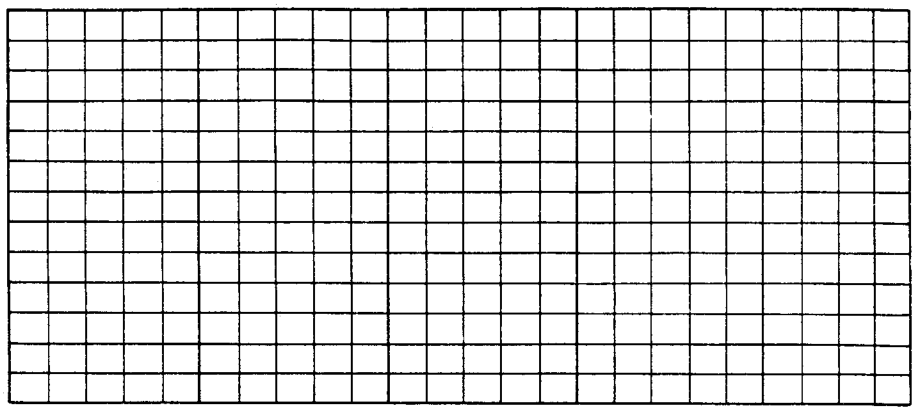
Specimen No.	1	2	3	4	5	6	7
Wet unit weight determinations							
Desired moisture content (%)							
Water added (g) or (mL) or (cm^3)							
Mass of mold + wet soil (g)							
Mass of mold (g)							
Mass of wet soil (g)							
Wet unit weight (kN/m^3)							
Moisture content determinations							
Dish No.							
Mass of dish + wet soil (g)							
Mass of dish + dry soil (g)							
Mass of dish (g)							
Mass of water (g)							
Mass of dry soil (g)							
Moisture content (% of dry mass)							
Dry unit weight determinations							
Dry unit weight (kN/m^3)							

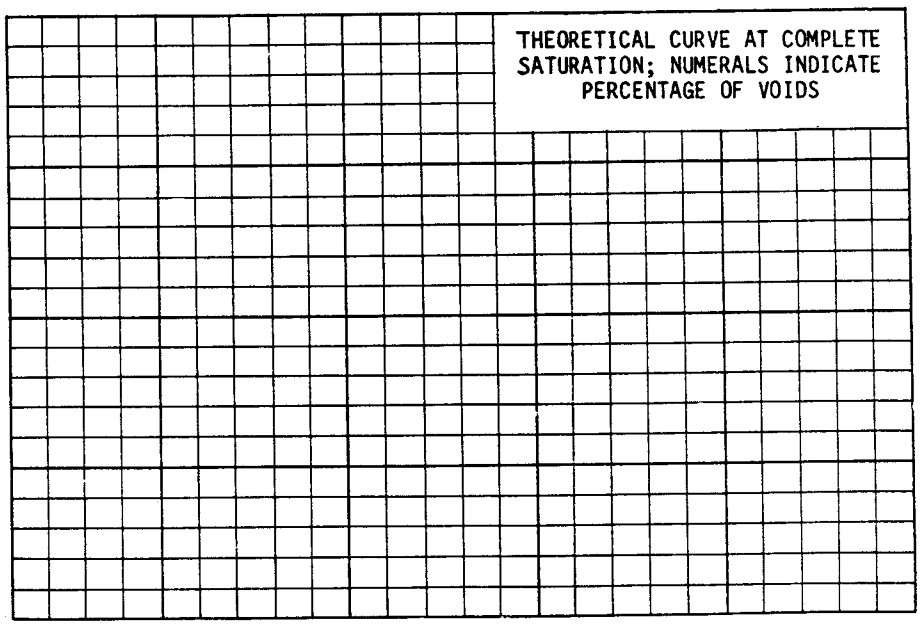
Comments:______________

Auxiliary tests:

USBR 5205-__ __
USBR 5300-__ __
USBR 5320-__ __

COMPACTION - PENETRATION RESISTANCE CURVES





CLASSIFICATION ________

GRAVEL ____%
SAND ____%
FINES ____%

ATTERBERG LIMITS

LIQUID LIMIT ____%
PLASTICITY INDEX ____%
SHRINKAGE LIMIT ____%

SPECIFIC GRAVITY

MINUS NO. 4 ____
PLUS NO. 4 ____
BULK ____
APPARENT ____
ABSORPTION ____%

COMPACTION

METHOD ________________
PERCENT LARGER THAN TESTED ____
MAXIMUM DRY UNIT WEIGHT ____ kN/m^3
OPTIMUM MOISTURE CONTENT ____%
DEGREE OF SATURATION ____%
PENETRATION RESISTANCE ____ kPa

NOTES ____

SAMPLE NO. ______________ HOLE NO. ______________ DEPTH ______________ ft

ADDED WATER DETERMINATION

FOR COMPACTION TEST SPECIMENS

Test designation USBR _____ - __ __

Project ____________________ Feature ____________________ Sample No. __________

Computed by ________________ Date __________ Checked by ________ Date __________

Specimen	Moisture content (%)			Mass (g)				
	Initial (1)	Desired (2)	Difference (3)	Specimen and container (4)	Container (5)	Specimen (6)	Dry mass of specimen (7)	Water to add (8)
			(2) - (1)			(4) - (5)	$\frac{(6)}{[100 + (1)]} \times 100$	$(7) \times \frac{(3)}{100}$

Comments: ____

Auxiliary Tests:

USBR 5300-__ __

GPO 846-285

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-922, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.