****Please note:** This is NOT the official training manual being used in the KDOT/KSU-Salina Certified Inspection and Testing Training (CIT^2) Program. This manual covers the same tests as the course manual and can be used as a reference guide for those tests. For more information about the training manual used in the CIT^2 Program, please contact Lora Kowach at (785)291-3836 or at lora@ksdot.org .

Report No. K-TRAN: KSU-96-10
Final Report

Soils Sampling and Testing Training Guide for Field and Laboratory Technicians on Roadway Construction

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December 1999

K-TRAN

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:
KANSAS DEPARTMENT OF TRANSPORTATION
THE KANSAS STATE UNIVERSITY
THE UNIVERSITY OF KANSAS

1. **Report No.** K-TRAN: KSU-96-10	2. **Government Accession No.**	3. **Recipient Catalog No.**
4 **Title and Subtitle** SOILS SAMPLING AND TESTING TRAINING GUIDE FOR FIELD AND LABORATORY TECHNICIANS ON ROADWAY CONSTRUCTION		5 **Report Date** December 1999 6 **Performing Organization Code**
7. **Author(s)** Eugune R. Russell, Michael Renk		8 **Performing Organization Report No.**
9 **Performing Organization Name and Address** Kansas State University Department of Civil Engineering Manhattan, Kansas 66506		10 **Work Unit No. (TRAIS)** 11 **Contract or Grant No.** C-937
12 **Sponsoring Agency Name and Address** Kansas Department of Transportation Docking State Office Bldg. Topeka, Kansas 66612		13 **Type of Report and Period Covered** Final Report October 1995 to December 1999 14 **Sponsoring Agency Code** 106-RE-0083-01
15 **Supplementary Notes**		

16 Abstract

This manual has been developed as a training guide for field and laboratory technicians responsible for sampling and testing of soils used in roadway construction. It was completed in conjunction with K-TRAN Project KSU-96-10, entitled "Pilot Study to Determine Personnel Certification and Training."

The development and implementation of Quality Control/Quality Assurance (QC/QA) specifications by the Kansas Department of Transportation has been a driving force behind the development of a soils training and certification program. Soils training and certification will increase the knowledge of laboratory, production, and field inspectors. Both the owner agency and the contractor will benefit with an increased number of qualified personnel to perform acceptance and quality control functions. In addition, it is anticipated that this program and its standardized set of core tests will help to achieve certification reciprocity throughout the region. This manual is a guide for training personnel to perform the core soils tests they should understand in order to be certified.

The manual is based on ASTM and AASHTO test methods and procedures. During the 4th Annual FHWA Region 5 & 7 Training and Certification Workshop, a core content of ASTM and AASHTO tests for soil technician training was defined by the Soils Training Development Team. This training manual implements this core content for certification of laboratory soil field inspectors.

17 **Key Words**		18 **Distribution Statement**	
Aggregate, Certification, Soils, Technician, Test Methods		No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19 **Security Classification (of this report)** Unclassified	20 **Security Classification (of this page)** Unclassified	21 **No. of pages** 248	22 **Price**

Form DOT F 1700.7 (8-72)

PREFACE

This research project was funded by the Kansas Department of Transportation K-TRAN research program and the Mid-America Transportation Center (MATC). The Kansas Transportation Research and New-Developments (K-TRAN) Research Program is an ongoing, cooperative and comprehensive research program addressing transportation needs of the State of Kansas utilizing academic and research resources from the Kansas Department of Transportation, Kansas State University and the University of Kansas. The projects included in the research program are jointly developed by transportation professionals in KDOT and the universities.

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SOILS SAMPLING AND TESTING TRAINING GUIDE FOR FIELD AND LABORATORY TECHNICIANS ON ROADWAY CONSTRUCTION

Mid-America Transportation Center Project:

"Pilot Study to Determine Personnel Certification and Training"

With Matching Funds from
Kansas Department of Transportation
K-TRAN Project, KSU-96-10

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Training Manual for Soil Technicians

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PREFACE

This manual is a product of K-TRAN Project KSU 96-10, entitled Pilot Study to Determine Personnel Certification and Training. It was developed as a training guide for field and laboratory technicians responsible for sampling and testing of soils used in roadway construction. During the 4^{th} annual FHWA Region 5 & 7 Training and Certification Workshop, a core content was defined by the Soils Training Development Team. This manual was developed in conjunction with this core content for Soil Field and Laboratory Inspectors. It is anticipated that the issue of reciprocity will be eliminated by implementing a standardized set of core tests throughout the region.

The development and implementation of Quality Assurance/Quality Control specifications by the Kansas Department of Transportation have been a driving force behind the development of a soils training and a certification program. Soils training and certification will increase knowledge of laboratory, production, and field inspectors. Both the owner agency and industry will benefit with an increased number of qualified personnel to perform acceptance and quality control functions.

This manual has been developed to follow ASTM/AASHTO test methods and procedures. Appendix 1 at the end of the manual contains ASTM/AASHTO test methods. The New England Transportation Technician Certification Program (NETTCP) soils manual was used as a model. The authors of this manual would like to express their gratitude to NETTCP.

CHAPTER I

Common Tests for Field and Laboratory Technicians

REDUCING FIELD SAMPLES OF AGGREGATE TO TEST SIZE

AASHTO T 248

1.0 Purpose

Aggregates and other field materials must be reduced to appropriate sizes for testing. With other factors being equal, larger samples will be more representative of the total supply. The methods that follow describe the reduction of a large field sample to a convenient size for conducting tests that will describe the material and measure its quality. These methods provide for reducing the large sample into a smaller one that is representative of the field sample and thus of the total supply.

Failure to follow the procedures in these methods correctly could provide a non-representative sample of the supply. The methods that follow should be used to minimize variations during handling.

2.0 Method Selection

Table 1 gives the appropriate splitting method for materials in various conditions.

Method A **Use the Mechanical (Riffle) Splitter for the following:**
Field samples of fine aggregates drier than Saturated Surface Dry (SSD)
Coarse aggregates drier than SSD
Mixtures of coarse and fine aggregates drier than SSD
Method B **Use Quartering for the following:**
Field samples of fine aggregates having free moisture on the particles surfaces (at SSD or wetter)
Coarse aggregates with free moisture on surface
Mixtures of coarse and fine aggregates with free moisture on surface
Method C **Use Miniature Stockpile Sampling for the following:**
Fine aggregates with free moisture on particle surface
Method C not permitted for coarse aggregates or mixtures of coarse and fine aggregates

Table 1: Splitting methods for various material conditions.

Saturated Surface Dry (SSD): State in which the aggregate is neither absorbing water nor giving off water. The aggregate does not contain free water on the surface.

3.0 Method A - Mechanical Splitter

Mechanical splitters (Figure 1) come in a variety of sizes. The splitter should have an even number of equal-width chutes. The chutes discharge alternatively to each side of the splitter. The sample size and type will dictate which splitter to use.

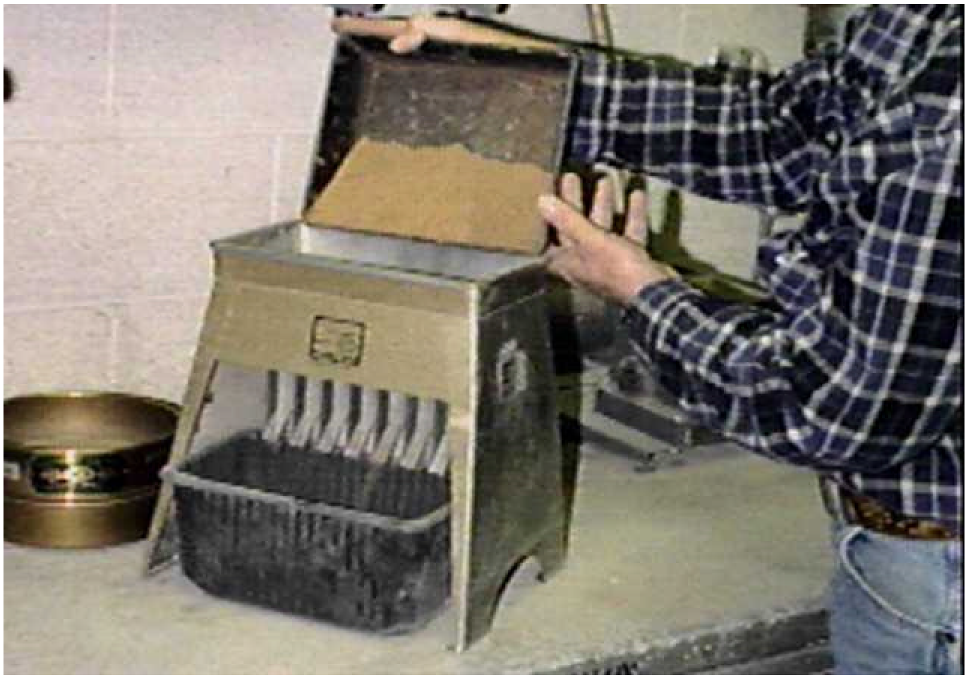


Figure 1: Mechanical Splitter

3.1 Mechanical Splitter requirements for coarse aggregates:

There must be at least eight chutes for coarse aggregates. Sample chutes for coarse aggregate must be at least 50% greater in width than the largest particle size in the sample. There must be receptacles which can contain the two halves of the sample being split and minimize loss of sample material.

3.2 Mechanical Splitter requirements for fine aggregates:

There must be at least 12 chutes for fine aggregates. Sample chutes for fine aggregates must be from 12.5 mm to 20 mm wide. There must be receptacles which can contain the two halves of the sample being split and minimize loss of sample material.

Figure 2: Equal amounts of sample should flow through each chute

3.3 Procedure

(1) Place the field sample into the hopper or pan and distribute from edge to edge. This will allow equal amounts of the sample to flow through each chute (Figure 2). The rate of sample introduction should be such that the material will flow freely through the chutes into the receptacles.

(2) Reintroduce the portion of the sample in one of the receptacles into the splitter as many times as necessary to reduce the sample to the specified size.

4.0 Method B - Quartering

The quartering method should be used when splitters are not available. This method will require the following equipment:

(1) Straight-edged scoop, shovel, or a trowel

(2) Broom or brush

(3) Canvas blanket approximately 2 m by 2.5 m in size

4.1 Procedure

(1) Place sample in a quartering box or pan. Mix the sample thoroughly (turn pile over itself at least three times).

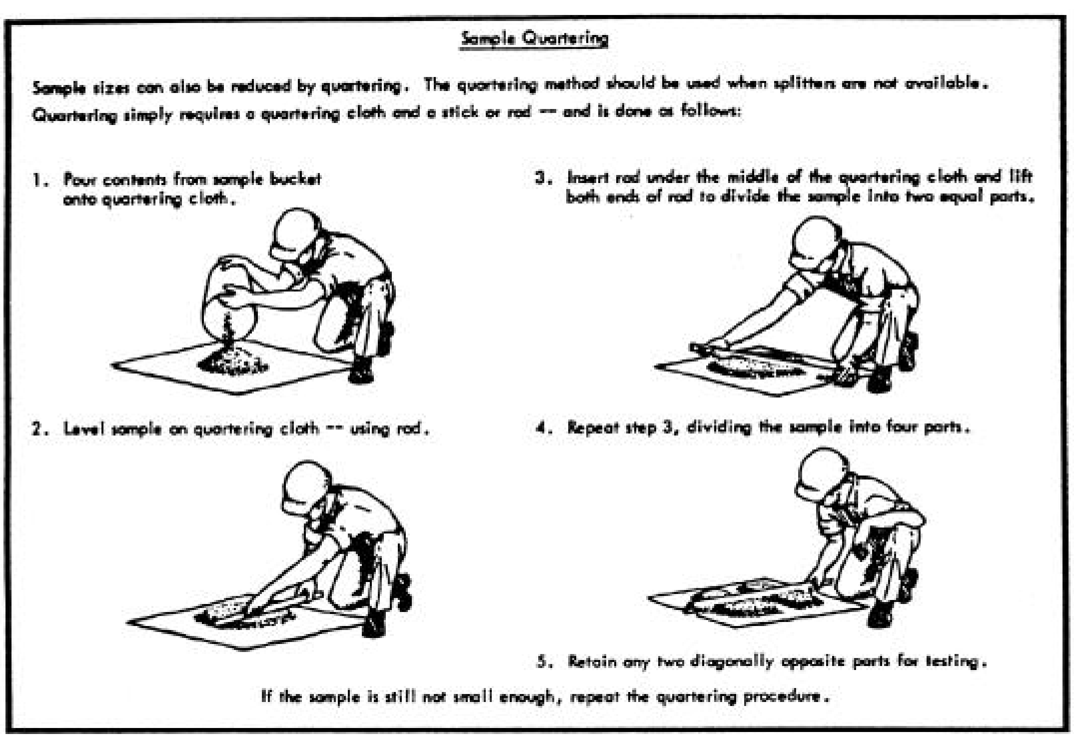


Figure 3: Quartering Method; reproduced from Asphalt Institute MS-22, p. 105

(2) Shovel the material into a layered conical pile by placing each shovel full on top of the previous. A pile with a diameter four to eight times its thickness should be created.

(3) Flatten the pile to a uniform thickness.

(4) Divide and separate the sample into four equal quarters.

(5) Remove two diagonally opposite quarters of the pile. Retain the remaining two quarters.

(6) Mix the remaining sample thoroughly and repeat the process until desired sample size is achieved.

5.0 Method C - Miniature Stockpile Sampling

This method requires the use of straight-edged scoop, shovel, or trowel to mix the aggregate. To sample the aggregate, either a small sampling thief, small scoop, or spoon should be used.

5.1 Procedure

(1) Place the damp fine aggregate sample in a splitting tray and mix it thoroughly. Adequate mixing should consist of turning the entire pile over at least three times.

(2) Shovel the sample into a conical pile. Each shovel full should be placed on top of the previous one, layering the pile.

(3) Representative samples should be taken from at least five locations in the pile using a large spoon or scoop.

Sample Test

<u>*True or False*</u>

1. Mechanical splitters are especially appropriate for fine aggregates in SSD condition.
2. For coarse aggregates, mechanical splitters should be set so that the openings are about 50% larger than the largest particles.
3. When using a mechanical splitter, the “chosen” half of the split sample should always be on the same side from which the last half was chosen.
4. The requirements for mechanical splitters stipulate that, for fine aggregates, there must be at least eight chutes with an equal width, which must be at least 50% greater than the largest particle size in the sample.
5. It is necessary to reduce field samples to test size because it minimizes the chance of variability in test results.
6. The miniature stockpile method is best for splitting samples of coarse aggregates.
7. When mixing a miniature stockpile, the sample should be turned over three or more times, and then shoveled into a conical pile.
8. The cone-and-quarter method is appropriate for splitting wet coarse aggregate samples.
9. The quartering method is not appropriate for splitting samples at SSD or wetter.
10. Test samples should always be placed in containers and labeled and tagged for easy identification.

11. The chute opening on riffle splitters for fine aggregates is required to be at least 20 mm wide.
12. When using the quartering method, after layering the pile and reducing it to a uniform thickness and dividing it into four quarters, perpendicular quarters should be chosen for the sample.

LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOILS

AASHTO T 265

1.0 Purpose

Moisture content is defined as the ratio of the weight of water to weight of soil solids and is generally expressed as a percentage. A material's moisture content determines its ability to be excavated, consolidated, moved, dried out, screened, or weighed. Moisture content values are useful in calculating a number of material properties, including density, plasticity, and permeability.

2.0 Apparatus

Source of Heat: a force-draft drying oven, capable of maintaining a temperature of 110° +/- 5°C (230° +/- 9°F) for non-organic soils.

Balance: general purpose, must meet the requirements of AASHTO M 231.

Containers: should be corrosion resistant and must not undergo changes in mass when subjected to repeated heating and cooling. Containers must have tight-fitting lids unless samples are weighed immediately upon removal from oven. A container without a lid may be used provided the moist or dried sample is weighed immediately after removal from the oven.

Stirrer : aid for water evaporation, mix sample during drying.

Desiccator : for soils where containers without tight-fitting lids are used.

3.0 Sample Size

Select a representative sample of soil in the amount specified by the test method. If no amount is indicated, a proper sample size should be selected from Table 1.

Maximum Particle Size, mm	Minimum Sample Size, grams
0.425 mm	10 g
4.75 mm	100 g
12.5 mm	300 g
25 mm	500 g
50 mm	1000 g

Table 1: Moisture content sample sizes

4.0 Procedure

(1) After the proper sample size is determined, obtain the sample and protect it from moisture loss during transport. Use an airtight container or plastic bag.

(2) Weigh a clean, dry container with its lid (W_c).

(3) Place the sample in the container and replace lid immediately. Weigh the container, including lid and sample (W_1).

(4) Remove the lid and place the container with sample in drying oven maintained at 110° +/- 5°C (230° +/- 9°F). Dry to a constant mass (Figure 1).

(5) Remove container from oven and immediately replace the lid. Allow sample to cool to room temperature.

6) Weigh the container including lid and dry sample (W_2).

Figure 1: Samples being dried in oven at 110° ± 5°C (230° ± 9°F)

If checking sample mass over successive periods to determine constant mass is found to be impractical, an overnight period of 15 or 16 hours is usually sufficient to dry to a constant mass. Samples can usually be dried to a constant mass in several hours.

Dry samples can absorb moisture from wet samples. Remove dried samples from oven before placing wet samples in oven.

5.0 Calculation

The calculation for moisture content (*w*) is as follows: divide the mass of moisture by the mass of oven-dry soil and multiply by 100. Calculate to the nearest tenth.

$$w \quad \frac{(W_1 \quad W_2)}{(W_2 \quad W_c)} \quad 100$$

where: w = moisture content (%)

W_1 = mass of container and moist soil (g)

W_2 = mass of container and oven-dried soil (g)

W_c = mass of container (g)

5.1 Example

Mass of Container, plus lid = 506.8 g

Mass of Container, plus lid and moist sample = 535.2 g

Mass of Container, plus lid and dried sample = 530.8 g

$$w \quad \frac{(535.2 \;\; 530.8)}{(530.8 \;\; 506.8)} \; X \; 100 \quad 18\%$$

Sample Test

<u>*True or False*</u>

1. The value of any soil's moisture content will always fall between 0 and 10%.
2. The minimum mass required for a soil sample with a maximum particle size of 25 mm is 500 grams.
3. It is advisable to remove dried samples from an oven prior to placing wet samples in the same oven.
4. Extra care should be taken when using a microwave to dry material to ensure that the particles are not cracking.
5. When transporting the sample to the testing facility, make sure it is in an airtight, sealed container to prevent the loss of moisture.
6. All soil samples for moisture content should be placed in the microwave.
7. Samples may be assumed to have dried to a constant mass when they have been in an oven for a length of time that has been previously demonstrated to achieve constant mass for samples of a similar nature with similar oven loading conditions.

<u>*Calculation*</u>

Mass of container	=	510.0 g
Mass of container and moist sample	=	538.4 g
Mass of container and dried sample	=	533.8 g

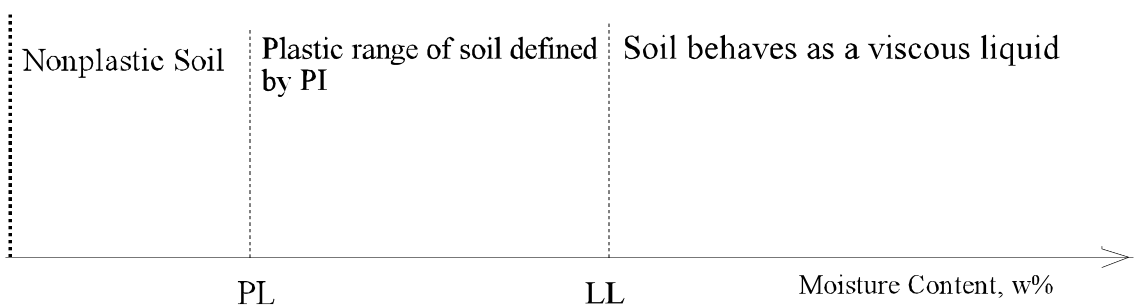
Determine the moisture content in the sample.

Determining the Liquid Limits of Soils

AASHTO T 89

1.0 Purpose

A soil's liquid limit is the moisture content at which the soil passes from a plastic to a liquid state. The liquid limit is useful in describing a soil's reaction with water. The liquid limit along with the plastic limit (AASHTO T 90) can be used to determine the Plasticity Index (PI), which is useful for soil classification and determining engineering properties of the soil.



2.0 Apparatus

Dish: A porcelain dish, preferably unglazed, or similar mixing dish about 115 mm in diameter.

Spatula: A spatula or pill knife having a blade of about 75 mm to 100 mm in length and about 20 mm in width.

Liquid Limit Device: See Figure 1. There are two types, manual or mechanically operated. Specifications for the manual and mechanically operated devices are identical except that the mechanical device is motorized. The mechanical devices must be shown to produce the same results as the manually operated device.

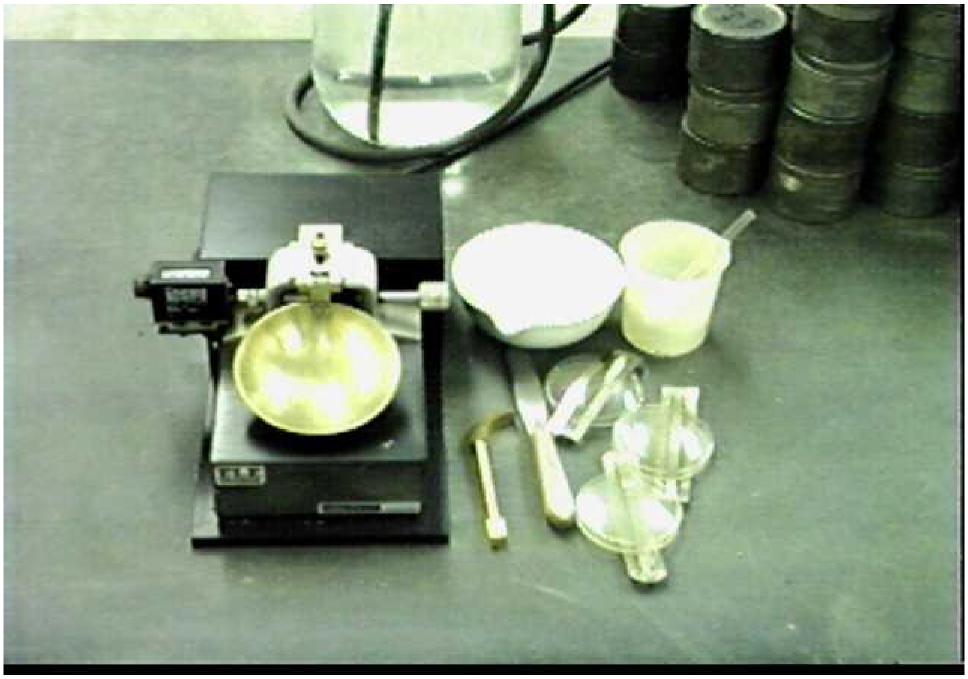


Figure 1: Liquid Limit Device and associated equipment

Manually Operated: Device consisting of a brass dish and carriage.

Mechanically Operated: Motorized device equipped to produce the rise and rate of shocks to a brass cup as required in this procedure.

<u>*Grooving Tool*</u>: A tool used to cut the soil pat in the liquid limit device. It is required to have the precise dimensions.

<u>*Gage*</u>: Can be attached to the grooving tool or separate. If separate, it may be a metal bar 10.0 +/- 0.2 mm thick and approximately 50 mm long. It must conform to the dimensions given.

<u>*Containers*</u>: Should be suitable for constant heating and cooling. The mass should not change and no disintegration should occur. Containers should also have close-fitting lids to prevent the loss of moisture prior to initial mass determination and to prevent absorption of moisture from the environment. One container is needed for each moisture content determination.

<u>*Balance*</u>: Must conform to AASHTO M 231. It must be class C with sensitivity to the nearest 0.01 g and a capacity of 1200 g.

<u>*Oven*</u>: A thermostatically controlled oven that is capable of maintaining a consistent temperature of 110 +/- 5°C (230 +/- 9°F).

3.0 Adjustment of Liquid Limit Device

The device should be inspected regularly to ensure that it is in good working order. An inspection should include an examination of the pin connecting the cup to make sure it is not worn sufficiently to allow side play, the screws connecting the cup and hanger arm should be checked to ensure they are tight, the points of contact on the cup and base should be checked for excessive wear, and the lip of the cup as well as the cup itself should be inspected to ensure the grooving tool has not worn away the surface. See Note 1 in AASHTO T 89 for direction as to the evaluation of worn liquid limit devices.

The height of the drop of the cup on the base should be checked and adjusted (Figure 2), if necessary, each time the test is run. The highest rise of the cup should be 10.0 +/- 0.2 mm from the point of contact on the base. The gauge should be used to check the drop height.

Figure 2: Checking height of liquid limit cup drop with height gauge.

See AASHTO T 89 (Note 2 and Figure 2) for method to check the actual drop height of the cup.

Figure 3: Place a piece of tape which bisects wear spot on bottom of liquid limit cup. This will provide the height gauge with a measuring point.

4.0 Sample Preparation

This procedure allows either a dry preparation (AASHTO T 87) or a wet preparation (AASHTO T 146). If determining the soil's liquid limit for structural purposes, use AASHTO T 146. All samples shall be taken from the portion passing the 0.425 mm sieve.

The choice of method depends on the condition of the sample and the time allotted to complete the test. AASHTO T87 requires one drying period, while AASHTO T146 requires two 12-hour drying periods before actually testing for the liquid limit.

The size of the sample depends on whether Method A or B is being used. Method A requires more material because it is a multipoint method. Method A needs approximately 100 g and Method B approximately 50 g.

5.0 Method A (Multi-Point Method)

Method A is required when running comparison or referee testing on a particular sample. It is generally considered a better indication of liquid limit of the material than the single point method (Method B).

1. Place the prepared 100 g soil sample in the mixing dish and thoroughly mix with 15 to 20 mL of distilled water. Mix by repeatedly stirring, kneading, and chopping with a spatula. Further additions of water should be made in 1 to 3 mL increments (Figure 4).

Figure 4: Add small increments of water when sample nears liquid limit.

Note: Tap water can be used if comparisons indicate that no difference in liquid limit occurs when using both types of water.

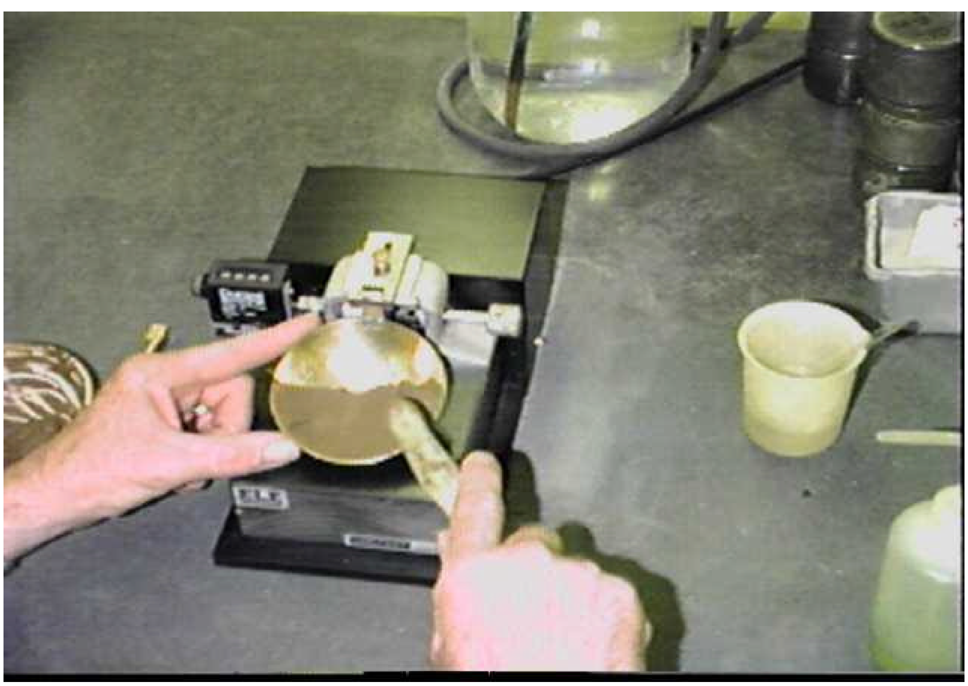


Figure 5: Squeezing and spreading sample into cup.

2. Add sufficient water to form a uniform mass of soil with a stiff consistency. Place enough material into the cup so that when it is squeezed and spread with the spatula the soil will rest in the cup above the spot where the cup rests on the base and will be a 10 mm thick at the point of maximum thickness (Figure 5).

   "As few strokes of the spatula as possible shall be used, care being taken to prevent the entrapment of air bubbles within the mass" (AASHTO T 89, 5.2).

3. Divide the soil in the cup with the grooving tool by making a smooth firm stroke perpendicular to the edge of the soil in the center of the cup (Figure 6). Cut the soil without allowing the soil pat to tear or slide within the cup itself. AASHTO T 89 allows up to 6 strokes of the grooving tool to make the cut. Only the last stroke is allowed to contact the cup surface. Wipe the grooving tool clean between cuts.

Figure 6: Dividing soil with AASHTO grooving tool.

When cutting the soil with the AASHTO grooving tool, the depth of the tool should be level with the depth of the soil. Other grooving tools that are available cut the soil pat to the proper 10 mm depth. However, if the AASHTO specification is to be followed, the initial depth prior to cutting is required to be 10 mm. Some experience will be necessary to gauge the relative volume of soil to place initially within the cup.

4. Once the groove has been cut, drop the cup by turning the crank at a rate of approximately two revolutions per second until the two halves of the soil pat come together along a distance of about 13 mm. Record the number of shocks required to close the groove. The base unit should not be held during this operation.

   AASHTO T 89 (Note 4) stipulates that for soils which tend to slide on the cup (as opposed to flowing), moisture should be added to the sample and the procedure should be repeated. If the soil continues to slide in the cup then it should be reported that the liquid limit of the material could not be determined.

5. Slice the soil pat with the spatula perpendicular and through the center of the previously cut groove (Figure 7). Obtain this cross-section of soil and place it into a container for moisture determination (Figure 8). The container should have a lid and should be tared to within 0.01 g. Determine the moisture content of the soil cross-section by drying in an oven regulated at 110 +/- 5°C (230 +/- 9°F) to a constant mass (Figure 9), determining the water loss, and expressing this as a percentage of the dry mass.

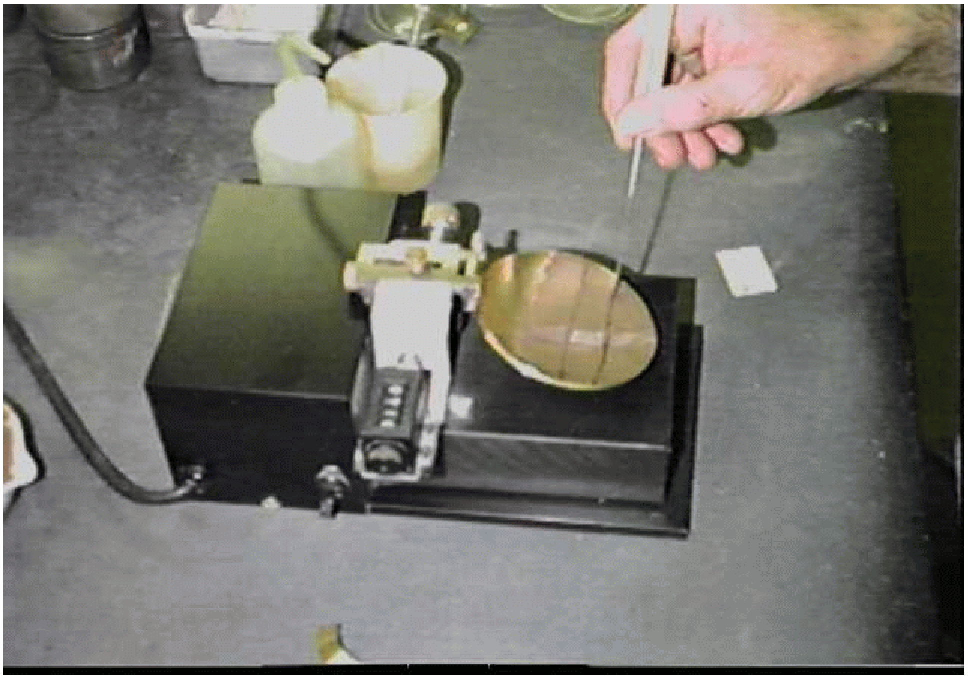


Figure 7: Slicing soil with spatula through previously-cut groove.

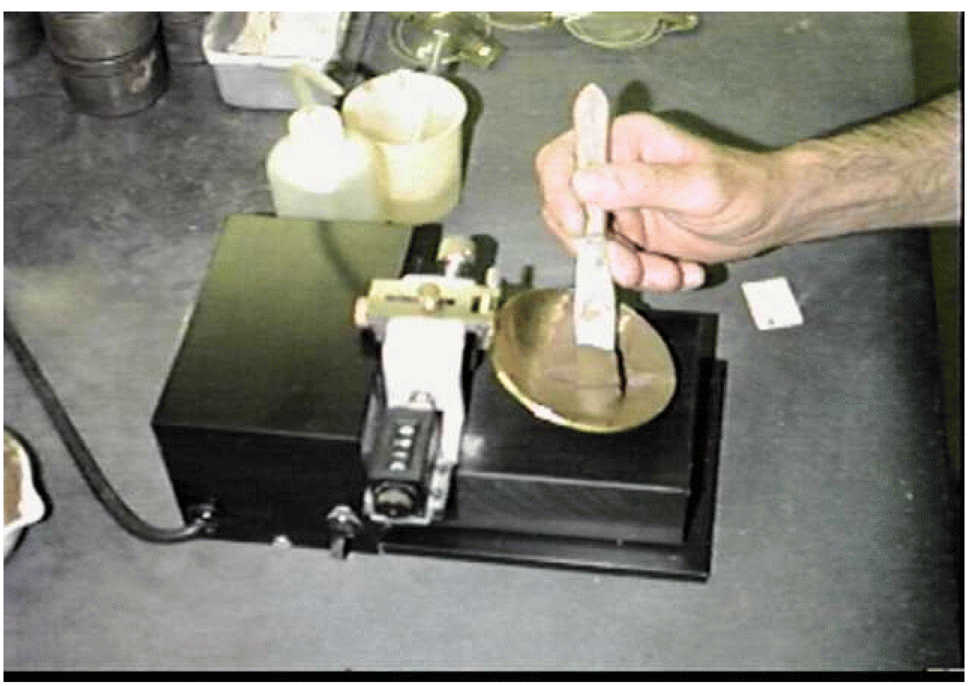


Figure 8: Obtain moisture sample with spatula.

6. Plac e the soil

rema ining in

the cup into the mixing dish and place additional water (1 to 3 mL) into the sample, or use previously prepared additional portions to which sufficient water has been added to result in a more fluid condition. "The object of this procedure is to obtain samples of such consistency that at least one determination will be made in each of the following ranges of shocks: 25-35, 20-30, 15-25, so the range in the three determinations is at least 10 shocks" (AASHTO T 89, 5.6).

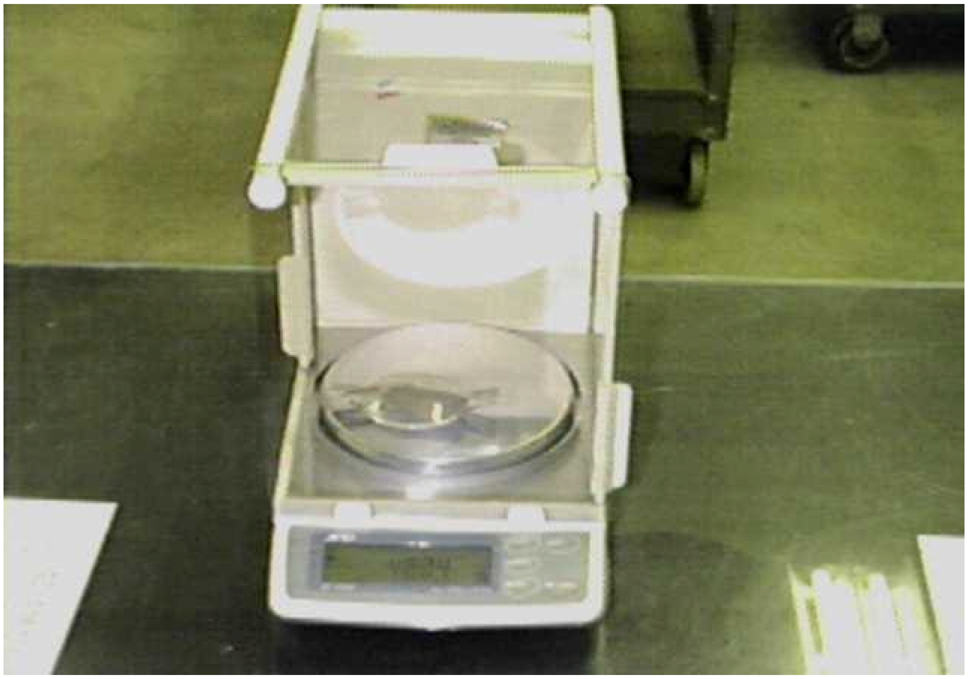


Figure 9: Weigh samples on balance with sensitivity to nearest 0.01g.

7. Calculate the water content for each sample by dividing the mass of water contained within the sample by the mass of the oven dried soil and multiplying by 100. For this procedure record moisture content to the nearest whole percent.

8. Prepare a flow curve (Figure 10) on a semi-logarithmic graph with moisture contents on the x axis and the corresponding number of shocks which closed the soil pat halves at least 13 mm on the y axis (number of shocks as ordinates on the logarithmic scale). The flow curve should be the straightest possible line drawn through three or more plotted points.

9. Determine the liquid limit as the moisture content which corresponds to the flow curve passing the 25 shock ordinate of the log scale. The following example illustrates a flow curve where the number of shocks (recorded on the curve) are plotted against the moisture content (recorded on the x-axis). In this case, the liquid limit would be 24 (24.24, rounded to the nearest whole number).

6.0 Procedure (Method B, Single-Point Method)

1. Prepare roughly 50 g of the soil and mix with roughly 8 to 10 mL of water and follow the mixing procedure for Method A, step 1.

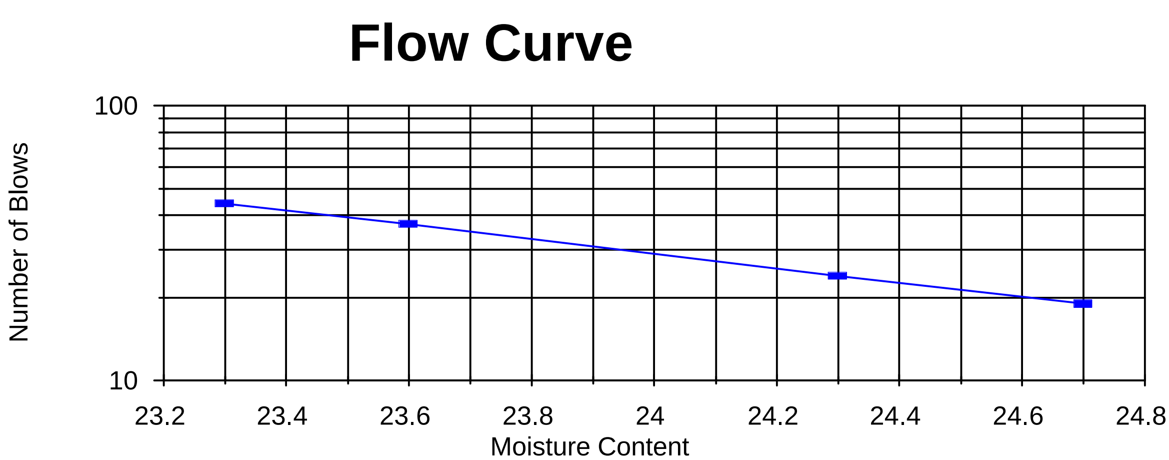


Figure 10: Flow Curve.

2. The procedure is identical to the Method A except that the soil pat should be prepared with water to produce a consistency which will close the two halves of the soil pat at least 13 mm within 22 to 28 shocks of the cup. AASHTO recommends running two liquid limit tests within the 22 to 28 shock range to ensure proper closure at the required number of shocks. “Groove closures between 15 and 40 blows may be accepted if variations of +/- 5% of the true liquid limit are tolerable” (AASHTO T 89, 10.3).
3. Determine the moisture content of the soil pat in accordance with AASHTO T 265.
4. The liquid limit for the single point method is derived from one of several means: the nomograph, the multi-curve, the slide rule with special blows scale, or by calculation. The standard three point method should be used as a referee test to settle all controversies (AASHTO T 89, 12.1).

   In most cases the determination of the liquid limit using the single point method is easiest using the Mean Slope Method, developed by the Army Corps of Engineers. The slope is reproduced on the following page from AASHTO T 89.

   For information on using the multi-curve or slide rule to determine liquid limit, please consult the appropriate section in AASHTO T 89.

7.0 Calculations

This example calculation demonstrates two trials using the single-point method (B). Liquid Limit is figured in the last column using the calculation found on the Nomograph in AASHTO T 89, Figure 4. Note that this calculation is based on the following equation:

$$LL \quad (Moisture\ Content) \times \left(\frac{Blows}{25}\right)^{0.121}$$

Tin #	Tin Mass (A), g	Tin w/ Wet Soil Mass (B), g	Wet Soils Mass (M_w) = (B-A)	Tin w/ Dry Soil Sample mass (C), g	Dry Soil Mass, (M_d) = (C-A)
1	14.176	23.178	9.002	6.064	2.938
2	14.433	25.453	11.020	21.867	7.434

Tin #	Loss, (L) = (M_w-M_d)	Moisture Content, (w) = (L/M_d) 100	Blows of LL Device, (N)	LL (equation)
1	2.938	48.4	24	48.2
2	3.586	48.2	23	47.7
	Avg			

Sample Test

True or False

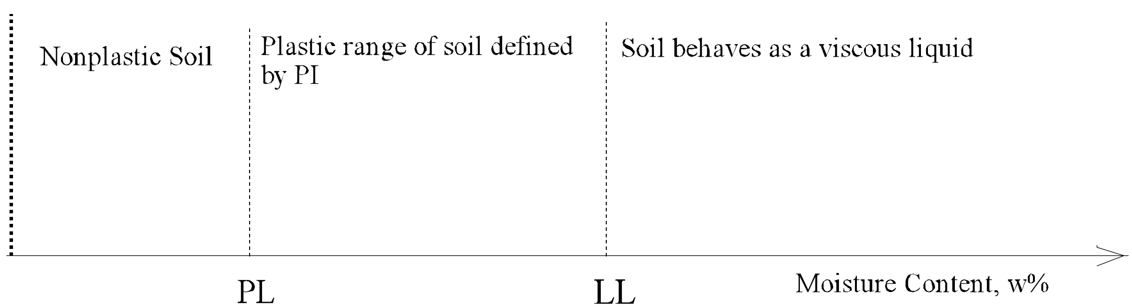
1. Liquid limit is used in conjunction with the moisture density relation to determine the plasticity index of soils.
2. The height of the drop of the LL cup should be checked and adjusted each time the test is run. The highest rise of the cup should be 10.0 +/- 0.2 mm.
3. The soil prepared for the liquid limit test should be passing the 4.75 mm sieve.
4. Mix the soil with water by alternately stirring, kneading, and chopping with a spatula.
5. If too much water is added to the sample then additional dry soil may be added to reduce overall moisture content.
6. Spread the prepared sample in the LL cup so that the soil is 10 mm thick at its thickest point.
7. When dividing the soil in the cup with the grooving tool, the division must be made in one cut or else the sample must be discarded.
8. Once the soil is cut, drop the cup by turning the crank at a rate of approximately two revolutions per minute.
9. The groove closure of the soil pat should be approximately 13 mm.
10. Soils should slide and not flow within the LL cup. If soils flow and do not slide, then the liquid limit may be indeterminable.

<u>Determining the Plastic Limit and Plasticity Index of Soils</u>

AASHTO T 90

1.0 Purpose

The plastic limit (PL), when used in conjunction with the liquid limit, is used internationally for soil identification and for strength correlations. The plastic limit is the lowest water content at which a soil remains plastic. When used with the liquid limit, the plastic limit will determine plasticity index. The plasticity index (PI) is the water content range within which a soil will be in a plastic state. The plasticity index is useful in soil classification and determining engineering properties of soils.



2.0 Apparatus

<u>*Dish*</u>: A porcelain evaporating dish or similar mixing dish should be used. It should be close to 115 mm in diameter and unglazed if possible.

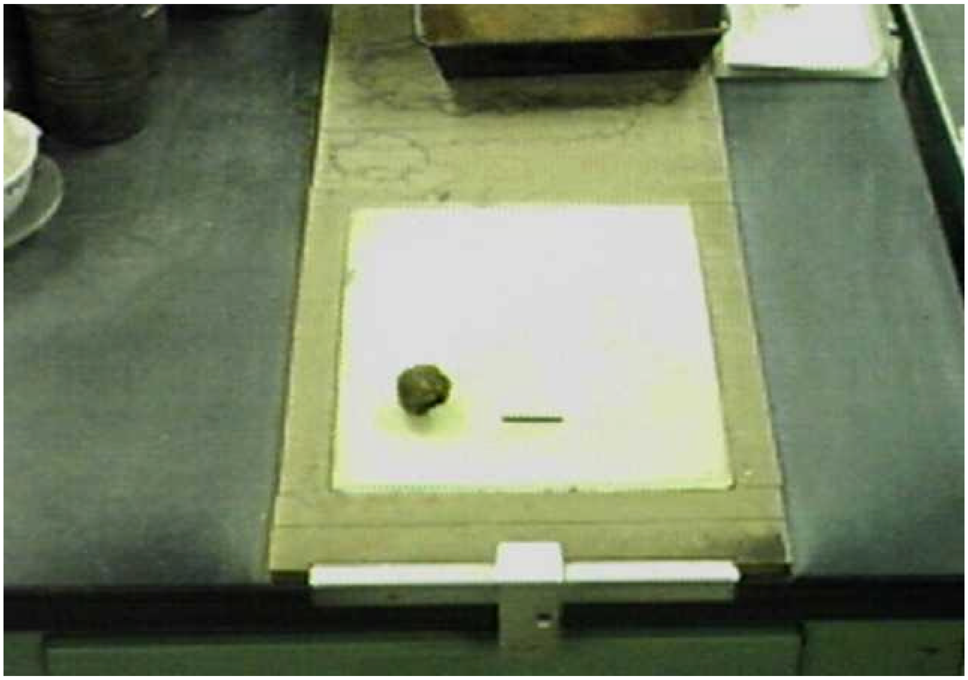


Figure 1: Sample on rolling surface.

Spatula: The spatula or pill knife should be approximately 75 mm in length and 20 mm in width. *Rolling Surface*: The sample should be rolled on a ground glass plate or a piece of smooth, unglazed paper (Figure 1).

Containers: Should be suitable for constant heating and cooling. The mass should not change and no disintegration should occur. Containers should also have close fitting lids to prevent the loss of moisture prior to initial mass determination and to prevent absorption of moisture from the environment. One container is needed for each moisture content determination.

Balance: Must conform to AASHTO M 231. It must be class C with sensitivity to the nearest 0.01 g and a capacity of 1200 g.

Oven: A thermostatically controlled oven that is capable of maintaining a consistent temperature of 110 +/- 5°C (230 +/- 9°F).

3.0 Sample Preparation

This test is usually run in conjunction with the liquid limit test. The sample for the plastic limit test should be obtained from the soil prepared for the liquid limit test. The sample can be obtained at any point in the mixing process where the soil is “plastic enough to be easily shaped into a ball without sticking to the fingers excessively when squeezed” (AASHTO T 90). Take a sample of approximately 8 g to run the plastic limit test.

If the sample will be used for the plastic limit test only, take a sample of about 20 g from the material passing the 0.425 mm sieve. Use either dry preparation (AASHTO T 87) or wet preparation (AASHTO T 146).

4.0 Test Procedure

(1) Place sample in mixing dish and thoroughly mix with distilled or demineralized water until the mass is plastic enough to be shaped into a ball. Take approximately 8 g of this sample to use in the plastic limit test.

(2) “Squeeze and form the test sample ... into an ellipsoidal-shape mass. Roll this mass between the fingers or palm and the ground-glass plate or a piece of paper lying on a smooth horizontal surface with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length (Figure 2). The rate of rolling, shall be between 80 and 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position again” (AASHTO T 90, 4.1).

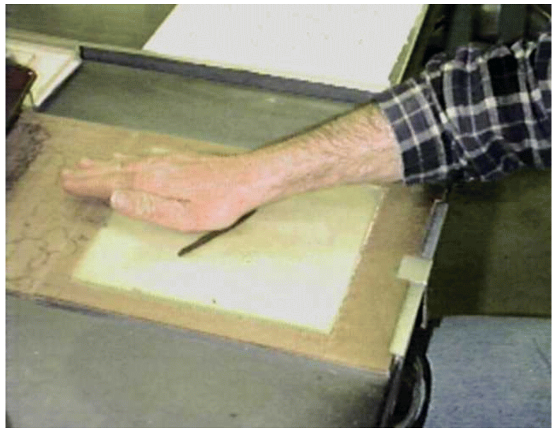


Figure 2: Rolling the plastic limit sample on the rolling surface.

(3)“When the diameter of the thread becomes 3.2 mm (Figure 3), break the thread into six or eight pieces (Figure 4). Squeeze the pieces, together between the thumbs and fingers of both hands into a uniform mass roughly ellipsoidal in shape and reroll. Continue this alternate rolling to a thread of 3.2 mm in diameter, gathering together, kneading and rerolling, until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread. The crumbling may occur when the thread has a diameter greater than 3.2 mm. This shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread 3.2 mm in diameter. At no time shall the operator attempt to produce failure at exactly 3.2 mm diameter by allowing the thread to reach 3.2 mm, then reducing the rate of rolling or the hand pressure, or both, and continue the rolling without further deformation until the thread falls apart. It is permissible to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal shaped mass nearer to required 3.2 mm diameter”(AASHTO T 90, 4.2).

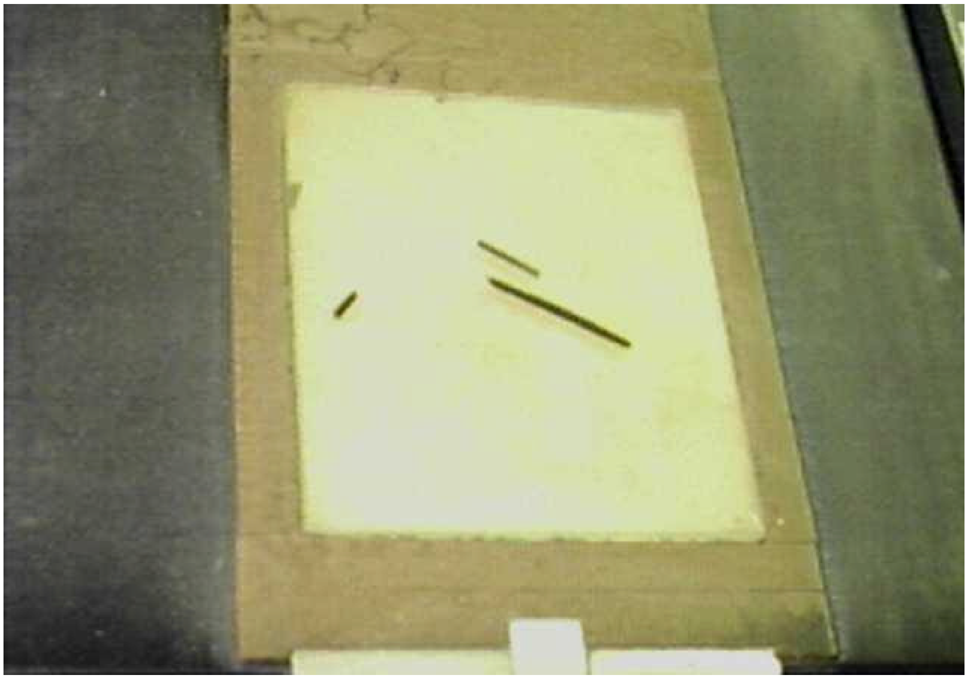


Figure 3: Roll into 3.2 mm diameter thread.

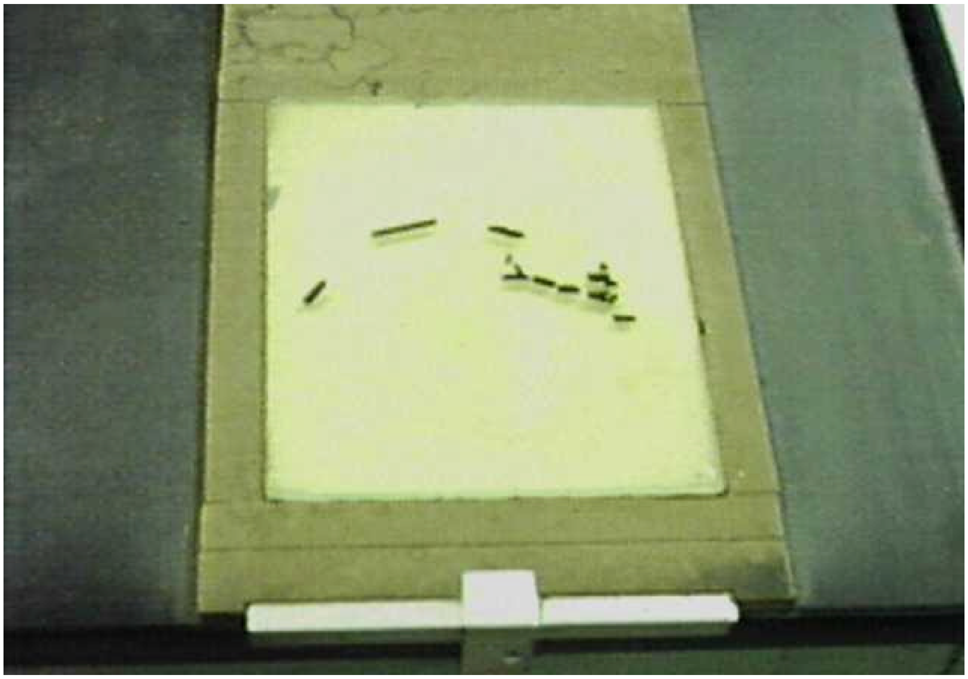


Figure 4: Break thread into 6 or 8 pieces

(4) Gather the portions of soil together and place in a suitable tared container; record the mass to the nearest 0.01 g. Dry the sample in accordance with AASHTO T 265 and record the dried sample mass to the nearest 0.01 g.

5.0 Calculations

5.1 Plastic Limit

The plastic limit (PL) is expressed as the water content in percentage of the mass of the oven-dry soil, as follows:

$$PL \quad \frac{Mass\ of\ Water}{Mass\ of\ Oven\ Dry\ Soil}\ X\ 100$$

The plastic limit should be reported to the nearest whole number.

5.2 Plasticity Index

The plasticity index (PI) is calculated as the difference between liquid limit (LL) and plastic limit as follow:

$$PI = LL - PL$$

When the liquid limit or plastic limit cannot be determined, record the plasticity index as NP (non-plastic). Also, if the plastic limit is greater than or equal to the liquid limit, record plasticity index as NP.

5.3 Example Calculation

Mass of tin, (M1)	Mass of tin w/wet soil, (M2)	Mass of tin w/ dry soil, (M3)	Wet soil mass, (M4)= (M2-M1)	Dry soil mass, (M5) = (M3-M1)	Mass of water, (M6) = (M4-M5)	PL = (M6/M5) 100
14.965 g	21.731 g	20.586g	6.766 g	5.621 g	1.145 g	20

Sample Test

True or False

1. The plastic limit is defined as the highest water content at which the material remains plastic.
2. The plastic limit is always at a higher water content than the liquid limit.
3. Distilled water should be used in preparing the sample for the liquid limit test if questions arise about the integrity of the tap water.
4. 8 grams of soil should be obtained to run the plastic limit test.
5. Samples should be rolled on a non-absorbent surface.
6. The soil should be rolled until it forms a thread approximately 3.2 mm in diameter.
7. The plasticity index is the sum of liquid limit and plastic limit.
8. If the liquid limit or plastic limit cannot be determined, report the plasticity index as zero.
9. The soil must crumble at 3.2 mm in order to be considered a satisfactory endpoint for the plastic limit.
10. It is permissible, for feebly plastic soils, to make the initial diameter of the ellipsoidal mass nearer to the required 3.2 mm when beginning the rolling process.

Calculation

Mass of Tin = 14.178 g

Mass of wet soil sample plus tin = 22.175 g

Mass of dry soil sample plus tin = 21.026 g

Calculate the plastic limit.

Mass of tin, (M1)	Mass of tin w/wet soil, (M2)	Mass of tin w/ dry soil, (M3)	Wet soil mass, (M4)= (M2-M1)	Dry soil mass, (M5)= (M3-M1)	Mass of water, (M6) = (M4-M5)	PL = (M6/M5) 100

Moisture-Density Relations Using a 2.5 kg Rammer and a 305 mm Drop

AASHTO T 99

1.0 Purpose

This procedure is also referred to as the standard proctor. It is used to determine the relation between moisture content and density of soils. The procedure ultimately determines the optimum moisture content (OMC) and maximum dry density (MDD).

The soil sample is prepared and compacted into a 100 mm or 150 mm diameter mold size using the 2.5 kg rammer and drop of 305 mm. The wet mass of the compacted sample is divided by the mold volume to yield the wet density. The dry density is determined by subsequent moisture content testing on the compacted mass of material. Density and moisture content are plotted over several moisture content values to determine optimum values (See Figure 1).

There are four alternative methods. The chosen method should be specified with regard to the material being tested. If no method is specified, Method A will govern.

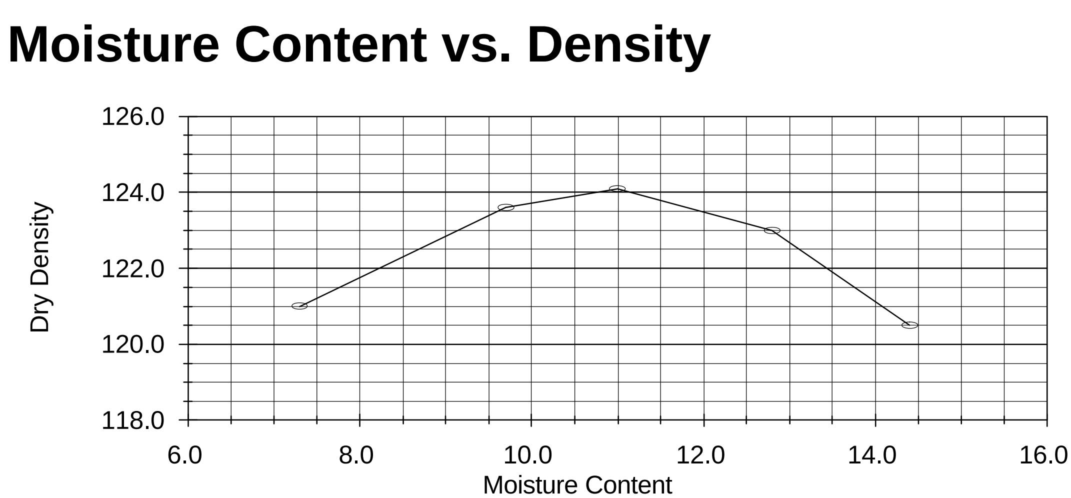


Figure 1: ***OMC occurs at approximately 13.0 and MDD is 124.1***

2.0 Apparatus for Standard Proctor

Rammer: See Figure 2.

- *Manually Operated Rammer*: See Figure 2. A manually operated metal rammer has a compacting head 50.8 mm (two in) in diameter and approximately 100 mm (4 in) in length, which is attached to the lower end of 9.5 mm (3/8 in) diameter rod approximately 550 mm (22 in) in length. Above the compacting head, a 50.8 mm (2 in) diameter steel weight with a hole drilled longitudinally through the center slides on the rod. The rod is provided with a stop so that when the weight is raised and released, it will fall a distance of 304.8 +/- 1.524 mm(12 +/- 1/16 in) to strike the head and impart compactive effort to the sample. The weight of the falling member is such as to overcome the inertia of the compacting head and impart a blow to the sample which is equivalent to that of 2.495 kg +/- 9 g (5.50 +/- 0.02 lb) rammer and having a free-fall of 304.8 +/- 1.524 mm(12 +/- 1/16 in).
- *Mechanical Compacting Rammer*: A mechanically operated rammer is equipped to control the height of the drop to 304.8 +/- 1.524 mm(12 +/- 1/16 in) above the elevation of the soil and has to distribute the blows over the soil surface. The rammer has a 50.8 mm (2 in) diameter, flat circular face and has a nominal weight of 2.495 kg +/- 9 g (5.50 +/- 0.02 lb). If a mechanical compacting ram is used then it must be calibrated to produce results repeatable with the manual methods using ASTM method D2168-90. The percentage difference of maximum dry unit mass values for a single set of data (the same sample ran through both manual and mechanical compaction procedures) may not exceed 2%, or the mechanical rammer apparatus may need to be adjusted. In addition to this density check, the deformation characteristics of both manual and mechanical compacting must be checked using a lead

mechanical compaction methods must not exceed 2%. Refer to ASTM D2168-90 for detailed procedures when calibrating mechanical rammers to manual rammers.

Molds: Depending on the method, either a 102 mm or a 152 mm mold, solid wall metal cylinder, with dimensions and capacities as shown in AASHTO T 99, Figure 1. For either the 102 mm or 152 mm molds the height is 116.43+/- 0.13 mm (4.584 +/- .005 in). Molds that fail to meet manufacturing tolerances after continued service may remain in use provided those tolerances are not exceeded by more than 50%; and the volume of the mold, calibrated in accordance with Section 7 of AASHTO T 19, for Unit Mass of Aggregate, is used in the calculations.

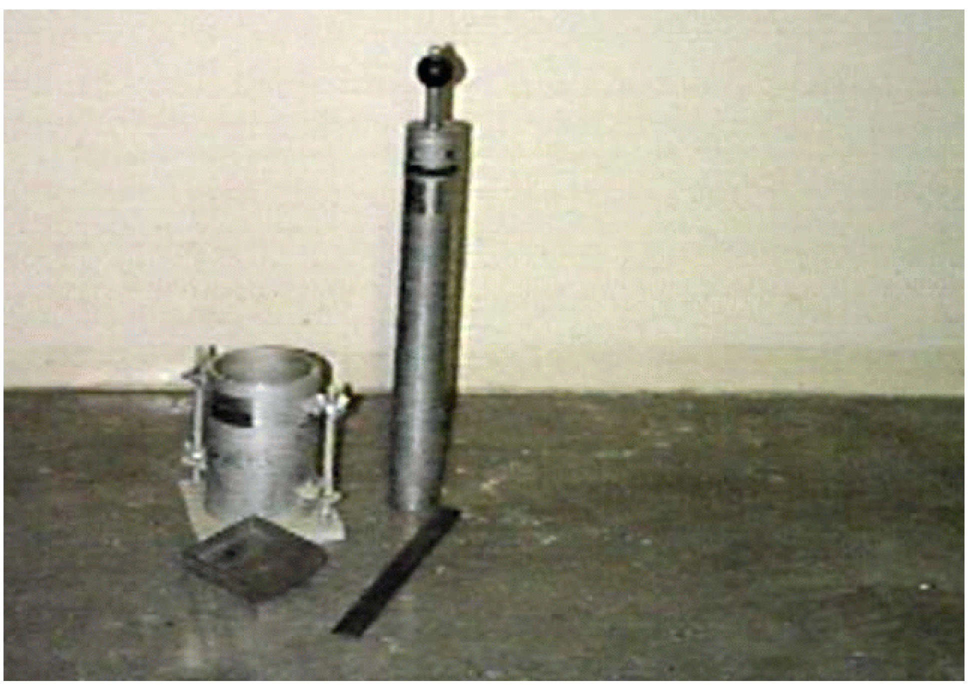


Figure 2: Apparatus for Standard Proctor.

Scales and balances: Must conform to requirements of AASHTO M 231, Class G20 and G2.

Drying Oven: Must be capable of maintaining a temperature of 110 +/- 5°C (230 +/- 9°F).

Straightedge: At least 50 mm length, made of hardened steel with one beveled edge. The straightedge is used to plane the surface of the soil even with the top of the mold. The straightedge may become beveled with use and should be checked periodically. The straightedge should not be so flexible as to cause a concave surface when trimming the soil from the top of the soil.

Sieves: 50 mm, 19.0 mm, and 4.75 mm sieves conforming to the requirements of AASHTO M 92.

Mixing Tools: Sample pans, spoons, scoops, trowels, used for mixing the sample with water.

Containers: Moisture resistant with close fitting lids to retain moisture content of prepared soil samples.

Miscellaneous: Graduated cylinders for adding water.

3.0 Test Methods

AASHTO T 99 stipulates four distinct test methods for these procedures: Method A, Method B, Method C, and Method D. The method to be used should be indicated in the applicable specification. If none is indicated, use Method A (AASHTO T 99, 1.2).

	Method A	Method B	Method C	Method D
Mold Size	101.60 mm	152.40 mm	101.60 mm	152.40 mm
Material Size	Passing 4.75 mm	Passing 4.75 mm	Passing 19.0 mm	Passing 19.0 mm
Blows per layer	25	56	25	56
Layers	3	3	3	3

Use caution when selecting the test method to be used. AASHTO test method designations are distinct from ASTM methods listed in D 698 and D 1557. ASTM contains three Methods (A, B, C) which correspond to different mold dimensions than their AASHTO counterparts.

AASHTO stipulates for each method that material must pass the designated sieve. Any material retained on the designated sieves is discarded, unless the oversize correction procedure is to be used.

4.0 Sample Preparation

1. If the sample is wet, dry it in an oven not exceeding 60°C (140°F) until it becomes friable under a trowel. Aggregations in a friable soil sample will break apart easily. Avoid breaking apart the natural particles when breaking up the soil aggregations.
2. Sieve the sample over the specified sieve for the Method being performed (A and B use a 4.75 mm sieve; C and D use the 19.0 mm sieve). Discard any material retained on the specified sieve.

   Rock Replacement: Note 7 in AASHTO T 99 states that “if it is advisable” to maintain the same percentage of coarse material in the lab sample as was found in the field, the material should be screened through a 50 mm and 19.0 mm sieves to ascertain the amount of material retained on the 19 mm sieve. Then an equal amount of material passing the 19 mm sieve but retained on the 4.75 mm sieve from the remaining portion of the sample should be recombined with the test sample prior to compaction. This procedure, when followed, necessitates a larger sample size than might ordinarily be obtained.

3. Thoroughly mix the remaining sample. Obtain at least enough material to prepare one "point" on the density curve. One "point" on the density curve would consist of enough material to fill the mold when compacted and provide enough extra material to ensure adequate material for increase in density as more water is added.

   In essence, this method uses the same soil sample for each "point" on the density curve. In some cases it may be necessary to prepare individual portions for each density "point" where soil or soil-aggregate mixtures are either too heavy-textured (silty or clayey materials), or where aggregates are prone to degradation from the repeated blows of the compaction rammer.

   In most cases enough material should be sampled from the field to permit four individual "points" of soils to be prepared at a range of moisture contents, beginning approximately 4% below the anticipated optimum moisture content, and then each subsequent "point" increased by 2% moisture. Optimum moisture content should be "bracketed" by the prepared samples in order to provide data for a more accurate moisture-density curve.

   "In instances where the soil material is fragile in character and will be reduced significantly in grain size by repeated compaction, a separate and new sample will be used in each compaction test" (AASHTO T 99, 4.4.1).

4. Prepare the sample(s) and mix with water to produce the desired moisture content. If the four "points" are prepared in advance make sure to store prepared material in moisture proof containers.

   Moisture is added to the soil or soil-aggregate material as a percentage of the sample's original mass. The following example illustrates this calculation:

° Given a sample of 6.09 kg, the sample needs to be prepared with approximately 2% additional moisture.

6.09 kg x 1.02% = 6.21 kg, i.e., enough water should be added to the sample to produce a sample of 6.21 kg.

(6.21 - 6.09) = 0.12 kg of water added to bring up the moisture content by approximately 2%

5.0 Procedure

1. Record the mass of the mold equivalent to tare weight of mold (without the extension collar) and record in kilograms to the nearest 5 grams.
2. Place a representative portion of the sample into the sample mold (102 mm diameter molds for Methods A and C, or a 152 mm diameter mold for Methods B and D) in order to fill it in three approximately equal layers (Figure 3) to give a total compacted depth of about 127 mm. Apply the required number of blows to the specimen layer (25 blows for Methods A and C, 56 blows for Methods B and D). Compact with the 2.495 kg rammer. Repeat this step for subsequent layers.

Figure 3: Adding a layer of soil.

The final specimen height after all layers have been compacted should be roughly 127 mm. When compacting the specimen using the manual rammer, uniformly distribute the blows over the entire surface area of the sample. At no time should the drop height vary from 305 mm. The technician should use care not to inadvertently lift the rammer and sleeve from the surface of the sample prior to compacting. The rammer and sleeve should also maintain a perpendicular orientation to the sample and mold during the compaction process (Figure 4). Clean the face of the hammer between lifts.

Figure 4: During compaction, technician should keep rammer perpendicular to the sample.

During the compaction process, the mold should rest “firmly on a dense, uniform, rigid, and stable foundation or base. This base shall remain stationary during the compaction process” (AASHTO T 99, 4.2).

Figure 5: Sawing motion removes material above the top of the mold.

3. Remove the extension collar from the mold and trim the soil or soil-aggregate sample even with the top edge of the mold using a straightedge (Figure 5). Remove any particles that lodged between the mold and the base plate or bolt holders. If gaps exist in the plane of the material fill in with loose soil collected around baseplate (Figure 6).
4. Weigh the mold with sample in kilograms and record to the nearest 5 grams.
5. When using the 102 mm mold (Methods A and C), multiply the wet mass of the soil (mold mass with sample minus mold mass) by 1060, and record the wet density of the soil, W1, in kilograms per cubic meter.

Figure 6: Add soil to any noticeable gaps in soil surface after it has been planed.

When using the 152 mm mold (Methods B and D), multiply the wet mass of the (mold mass with sample minus mold mass) by 471, and record the wet density of the soil, W1, in kilograms per cubic meter.

6. Remove the compacted soil or soil-aggregate sample from the mold and slice vertically through the center of the specimen. Obtain a representative sample from one of the cut faces, determine the moist mass immediately and record and record and dry in accordance with AASHTO T 265 to determine moisture content.

7. Break up the remainder of the sample of the mold until it is judged by eye to completely pass a 4.75 mm sieve for Methods A and B. When using Methods C or D, break up the particle aggregates until those particles which are agglomerated will completely pass a 19.0 mm sieve and 90% of the fines in the sample will pass a 4.75 mm sieve. Add the broken up sample to the remainder of the sample being used for the test.

8. Add additional moisture to the sample so that the overall increase is approximately 2%. In no case should the increased water content be more than 4%. If separate density points were prepared prior to performing the procedure, then this step may be skipped. Continue compacting samples with moisture contents increasing by roughly 2% until there is a drop or no change in the calculated wet density, W1.

6.0 Calculations

1. Calculate the wet density (W_1) in kilograms per cubic meter

   Methods A and C: (mass of mold and soil - mass of mold) x 1060

   Methods B and D: (mass of mold and soil - mass of mold) x 471

2. Calculate the moisture content for each compacted sample by dividing the water content (loss between wet mass and dry mass for moisture sample) by the dry mass of the sample by multiplying by 100.

$$w = \left(\frac{M_1\ M_2}{M_2}\right)\ X\ 100$$

   w = moisture content of sample

   M_1 = wet mass of soil

   M_2 = dry mass of soil

3. Calculate the dry density (W) in kg/m^3 for each compacted sample in kilograms per cubic meter.

W=

$$\left(\frac{W_1}{w\ 100}\right)\ x\ 100$$

4. Determine the moisture-density relationship by plotting density as the ordinates and the corresponding moisture contents as the abscissas.
5. Connect the points drawn on the moisture-density graph with a smooth curve. The moisture content corresponding to the peak of the curve will be termed the optimum moisture content.
6. The dry density at the optimum moisture content is the maximum dry density.

7.0 Example Calculation

Mass of Mold(kg) 4.29

Soils Test
Standard Compaction Test- AASHTO T 99

Point #	Mass of mold and soil (kg)	Mass of wet soil (kg)	Wet density in Kg/m^3 (W1)
1	6.30	2.01	2130.6
2	6.38	2.09	2215.4
3	6.40	2.11	2236.0
4	6.42	2.13	2257.8

Moisture Contents

Point #	Mass of container and wet soil (g)	Mass of container and dry soil (g)	Mass of container (g)	Moisture content (*w*)	Dry density (W) in kg/m^3; (W1/*w*+100)*100
1	370.9	356.4	115.2	6.0	2008.1
2	395.6	376.5	123.2	7.5	2060.8
3	384.9	362.9	115.4	8.9	2051.4
4	386.2	360.8	122.8	10.7	2035.6

Sample Test

True or False

1. The moisture-density relation determines the mass of soil in a known volume mold in order to calculate the density of the material.
2. Soil samples for the moisture density test are prepared so that each point is increased or decreased approximately 2% in moisture.
3. Separate soil samples must always be prepared for separate points on the moisture-density curve.
4. The mass of the empty mold with the collar should be recorded as the mold tare mass.
5. When running AASHTO T 99, fill the mold in approximately five equal layers.
6. Methods A and C require 25 blows of the rammer per lift.
7. Moisture samples should be obtained from the compacted specimen by slicing vertically through the center of the specimen and obtaining a representative portion from one of the cut faces.
8. Moisture content is expressed as a percentage of the wet mass of the soil.
9. During the compaction process, the mold should rest on a dense, uniform, rigid and stable foundation or base.
10. Maximum dry density is expressed as a density number with a corresponding moisture content.

Sample Test

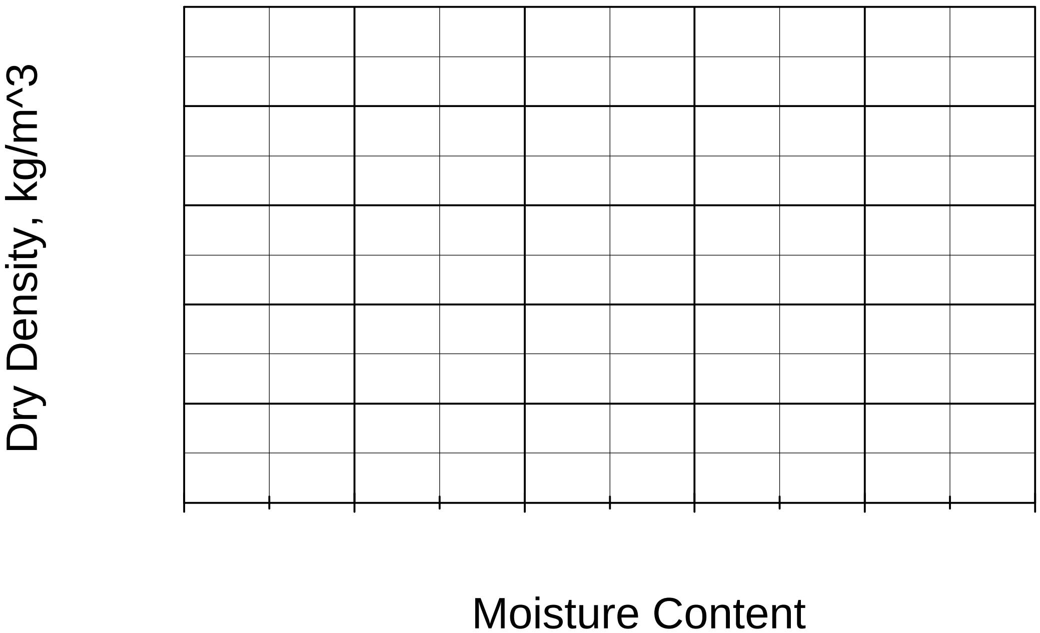
Calculation

Mass of Mold (kg) 6.53

Soils Test Standard Compaction Test- AASHTO T 99			
Point #	Mass of mold and soil (kg)	Mass of wet soil (kg)	Wet density (W1)
1	11.11		
2	11.36		
3	11.39		
4	11.24		

Moisture Contents					
Point #	Mass of container and wet soil (g)	Mass of container and dry soil (g)	Mass of container (g)	Moisture content (*w*)	Dry density (W) in kg/m^3; (W1/*w*+100) 100
1	361.9	347.8	115.2		
2	460.1	436.6	123.2		
3	505.1	471.9	115.4		
4	418.4	391.2	122.8		

Dry Density vs. Moisture Content



CHAPTER II

Soil Field Technician

STANDARD TEST METHOD FOR RANDOM SAMPLING

ASTM D3665

1.0 Scope

This method is used to eliminate any bias in materials sampling. Bias can be harmful even when it is unintentional. Technicians can easily fall into predictable sampling patterns that are biased.

The use of this method will eliminate the possibility for bias by implementing a set of numbers from a random number table. The numbers are then used to quantify sampling locations within the lot or sublot. This method describes how to determine sampling times and locations.

2.0 Sampling Definitions

A **lot** is the quantity of material evaluated by quality control procedures. The lot is a predetermined unit. Some examples of lots are a day's production, an interval of time, or a truckload of material. **Sublots** are portions which comprise the lot. The agency will specify how many sublots represent the lot. The random sampling procedures in this section determine when sublots should be obtained.

3.0 Straight Random Sampling vs. Stratified Random Sampling

The agency will specify whether to use straight or stratified random sampling. In straight random sampling, the entire lot is considered as a single unit and the determination of sample location is based on the entire lot size. Stratified random sampling divides the lot into a specified number of sublots and determines sample location within the specific sublots.

4.0 Sampling for Control vs. Acceptance

Quality Assurance is a concept that includes the functions of **process control, quality acceptance, and independent assurance (IA).** These are the necessary activities to verify, evaluate, and audit quality.

Quality control (QC) is also known as the process control function. QC testing is the responsibility of the material's producer. Sampling for QC is performed daily on the material during production. This provides data for instant evaluation should the material need to be controlled. Quality cannot be tested or inspected into the product, it must be present from step 1 of the project.

Quality acceptance (QA) testing is performed on produced material to determine conformance to specification requirements. QA samples may be obtained independently or on a comparison basis with QC testing. It is common for agencies to specify frequencies for QA samples at longer intervals than for QC samples.

Independent assurance (IA) is a management tool that requires a third party, without responsibility for QC or QA functions, to provide an independent assessment of the product. Independent assessments are performed to determine the reliability of process control and acceptance testing. The results of IA testing should not have a bearing on acceptance of the product.

5.0 Using the Random Number Table

1. Table 1, which is adapted from ASTM D 3665, contains three-digit numbers from 0.001 to 1.000.
2. Point to a number on the table without looking. The use of a pointed object may be advantageous. The number that is picked will establish the location of the sought-after number.
3. The first two digits of the three-digit number locate the line(row) number. The line number is the vertical column on the table's left side. For example, if you point to 0.156 in step 2, you will be looking for line 15.
4. Repeat step 2 and use the first digit to locate your column number. If you point to 0.469, then use column 4.
5. The location of the random number will be the intersection of your line and column numbers. Using line 15 and column 4, we will get a random number of 0.253.

Any page of the table can be used, but be sure to alternate pages between successive uses. The table must be entered separately for any and all numbers selected. If an unusable number is obtained, repeat the selection procedure. If this procedure is followed correctly, bias will be eliminated.

Table 1:
Random Number Table (Adapted from ASTM D 3665)

	0	1	2	3	4	5	6	7	8	9
1	0.534	0.323	0.402	0.460	0.391	0.920	0.610	0.793	0.924	0.595
2	0.887	0.518	0.905	0.269	0.109	0.546	0.340	0.276	0.975	0.583
3	0.843	0.722	0.639	0.638	0.028	0.740	0.625	0.724	0.995	0.178
4	0.735	0.147	0.463	0.748	0.721	0.369	0.202	0.020	0.299	0.088
5	0.582	0.118	0.665	0.849	0.160	0.164	0.613	0.246	0.227	0.528
6	0.040	0.687	0.313	0.200	0.916	0.387	0.862	0.655	0.739	0.022
7	0.718	0.590	0.494	0.836	0.013	0.769	0.853	0.056	0.109	0.946
8	0.934	0.094	0.049	0.447	0.543	0.155	0.408	0.439	0.723	0.642
9	0.879	0.971	0.985	0.973	0.461	0.144	0.654	0.627	0.735	0.954
10	0.516	0.146	0.912	0.354	0.155	0.488	0.068	0.219	0.307	0.005
11	0.756	0.174	0.525	0.586	0.650	0.070	0.703	0.341	0.740	0.772
12	0.734	0.234	0.921	0.787	0.507	0.573	0.680	0.141	0.681	0.525
13	0.700	0.635	0.750	0.104	0.190	0.760	0.570	0.464	0.798	0.473
14	0.454	0.067	0.700	0.952	0.909	0.645	0.050	0.198	0.466	0.889
15	0.465	0.514	0.947	0.210	0.253	0.882	0.396	0.808	0.164	0.396
16	0.919	0.605	0.422	0.835	0.552	0.689	0.475	0.574	0.678	0.006
17	0.020	0.504	0.877	0.852	0.307	0.220	0.288	0.711	0.534	0.626
18	0.177	0.873	0.978	0.285	0.607	0.095	0.212	0.917	0.553	0.502
19	0.284	0.997	0.787	0.792	0.453	0.950	0.192	0.849	0.645	0.689
20	0.356	0.340	0.666	0.841	0.713	0.593	0.537	0.662	0.604	0.158
21	0.670	0.481	0.254	0.663	0.112	0.923	0.819	0.631	0.382	0.603
22	0.498	0.628	0.930	0.991	0.650	0.680	0.840	0.035	0.139	0.714
23	0.685	0.627	0.107	0.376	0.957	0.697	0.619	0.315	0.173	0.684
24	0.278	0.582	0.535	0.951	0.004	0.658	0.067	0.798	0.142	0.774
25	0.111	0.156	0.709	0.932	0.004	0.731	0.234	0.290	0.886	0.016

	0	1	2	3	4	5	6	7	8	9
26	0.856	0.021	0.489	0.609	0.492	0.341	0.919	0.999	0.987	0.920
27	0.446	0.550	0.151	0.124	0.740	0.463	0.137	0.187	0.496	0.868
28	0.751	0.314	0.657	0.718	0.829	0.257	0.093	0.926	0.459	0.663
29	0.739	0.069	0.812	0.222	0.327	0.562	0.006	0.586	0.192	0.541
30	0.593	0.047	0.795	0.017	0.266	0.661	0.565	0.772	0.092	0.624
31	0.997	0.021	0.846	0.997	0.717	0.788	0.210	0.267	0.282	0.931
32	0.336	0.334	0.807	0.445	0.327	0.399	0.755	0.134	0.859	0.078
33	0.899	0.366	0.095	0.873	0.873	0.730	0.469	0.661	0.001	0.041
34	0.048	0.826	0.644	0.529	0.328	0.406	0.262	0.367	0.896	0.929
35	0.808	0.873	0.728	0.114	0.644	0.227	0.953	0.924	0.145	0.537
36	0.192	0.905	0.771	0.050	0.576	0.170	0.378	0.317	0.669	0.311
37	0.525	0.844	0.372	0.354	0.123	0.464	0.606	0.694	0.803	0.100
38	0.448	0.832	0.989	0.322	0.888	0.995	0.596	0.045	0.296	0.703
39	0.353	0.152	0.993	0.691	0.517	0.205	0.455	0.290	0.405	0.865
40	0.800	0.570	0.565	0.796	0.481	0.976	0.885	0.406	0.227	0.650
41	0.632	0.907	0.628	0.444	0.184	0.040	0.913	0.080	0.534	0.371
42	0.716	0.088	0.913	0.806	0.512	0.957	0.278	0.577	0.874	0.148
43	0.580	0.201	0.467	0.152	0.469	0.541	0.205	0.546	0.138	0.848
44	0.082	0.517	0.512	0.926	0.987	0.265	0.240	0.188	0.179	0.561
45	0.928	0.879	0.417	0.257	0.284	0.600	0.103	0.413	0.327	0.941
46	0.771	0.339	0.267	0.381	0.568	0.115	0.395	0.703	0.457	0.920
47	0.801	0.725	0.902	0.974	0.445	0.838	0.672	0.656	0.521	0.913
48	0.853	0.867	0.250	0.935	0.378	0.241	0.934	0.086	0.585	0.354
49	0.146	0.503	0.088	0.220	0.046	0.358	0.616	0.539	0.481	0.149
50	0.594	0.585	0.668	0.267	0.709	0.061	0.630	0.483	0.881	0.043

	0	1	2	3	4	5	6	7	8	9
51	0.500	0.857	0.222	0.308	0.325	0.216	0.057	0.635	0.265	0.384
52	0.209	0.188	0.776	0.478	0.247	0.836	0.038	0.277	0.140	0.109
53	0.991	0.886	0.753	0.375	0.855	0.290	0.281	0.781	0.895	0.831
54	0.300	0.982	0.275	0.097	0.942	0.406	0.810	0.190	0.020	0.874
55	0.023	0.352	0.343	0.772	0.053	0.781	0.265	0.454	0.118	0.504
56	0.988	0.470	0.154	0.504	0.911	0.520	0.582	0.125	0.367	0.921
57	0.407	0.869	0.615	0.392	0.361	0.857	0.846	0.004	0.425	0.466
58	0.571	0.585	0.159	0.637	0.122	0.521	0.732	0.249	0.465	0.335
59	0.709	0.156	0.414	0.975	0.425	0.433	0.366	0.883	0.736	0.084
60	0.560	0.806	0.766	0.555	0.303	0.439	0.193	0.707	0.649	0.533
61	0.049	0.017	0.990	0.784	0.796	0.832	0.056	0.179	0.079	0.479
62	0.153	0.700	0.390	0.283	0.360	0.602	0.103	0.061	0.089	0.924
63	0.664	0.139	0.356	0.892	0.417	0.554	0.596	0.376	0.842	0.291
64	0.465	0.553	0.170	0.987	0.182	0.009	0.767	0.131	0.615	0.824
65	0.330	0.306	0.794	0.814	0.421	0.421	0.450	0.875	0.137	0.750
66	0.843	0.818	0.866	0.358	0.069	0.497	0.848	0.003	0.602	0.787
67	0.065	0.926	0.565	0.256	0.149	0.849	0.907	0.577	0.863	0.940
68	0.152	0.229	0.924	0.341	0.080	0.847	0.274	0.999	0.824	0.921
69	0.708	0.593	0.775	0.055	0.226	0.540	0.989	0.915	0.838	0.334
70	0.103	0.190	0.269	0.676	0.672	0.101	0.383	0.453	0.733	0.575
71	0.147	0.452	0.051	0.217	0.042	0.250	0.043	0.812	0.133	0.530
72	0.509	0.934	0.166	0.267	0.684	0.876	0.657	0.890	0.585	0.048
73	0.466	0.454	0.845	0.287	0.793	0.701	0.178	0.707	0.299	0.831
74	0.804	0.464	0.866	0.294	0.413	0.774	0.427	0.508	0.372	0.350
75	0.884	0.099	0.329	0.791	0.869	0.650	0.346	0.983	0.884	0.972

	0	1	2	3	4	5	6	7	8	9
76	0.824	0.536	0.440	0.783	0.647	0.410	0.605	0.376	0.399	0.034
77	0.530	0.675	0.006	0.614	0.125	0.790	0.300	0.943	0.516	0.109
78	0.113	0.421	0.903	0.030	0.007	0.269	0.024	0.083	0.647	0.003
79	0.169	0.051	0.109	0.337	0.821	0.209	0.093	0.716	0.666	0.079
80	0.350	0.404	0.467	0.774	0.859	0.503	0.775	0.124	0.896	0.504
81	0.660	0.504	0.110	0.802	0.100	0.773	0.426	0.103	0.963	0.438
82	0.317	0.890	0.711	0.320	0.685	0.127	0.208	0.233	0.756	0.623
83	0.016	0.176	0.047	0.012	0.450	0.610	0.311	0.100	0.932	0.235
84	0.843	0.922	0.121	0.209	0.687	0.280	0.341	0.791	0.654	0.694
85	0.001	0.861	0.961	0.042	0.063	0.175	0.357	0.455	0.324	0.249
86	0.192	0.674	0.193	0.660	0.661	0.739	0.383	0.902	0.116	0.820
87	0.432	0.637	0.450	0.269	0.437	0.458	0.930	0.669	0.257	0.510
88	0.771	0.754	0.910	0.508	0.432	0.342	0.983	0.388	0.352	0.712
89	0.227	0.409	0.986	0.111	0.804	0.207	0.472	0.853	0.773	0.229
90	0.351	0.673	0.534	0.144	0.925	0.249	0.952	0.453	0.612	0.722
91	0.192	0.970	0.103	0.614	0.022	0.783	0.690	0.082	0.857	0.455
92	0.267	0.531	0.129	0.888	0.469	0.760	0.103	0.306	0.345	0.188
93	0.507	0.477	0.057	0.536	0.318	0.802	0.650	0.296	0.486	0.649
94	0.654	0.901	0.532	0.898	0.445	0.696	0.280	0.098	0.643	0.044
95	0.104	0.166	0.508	0.585	0.723	0.876	0.616	0.999	0.827	0.123
96	0.599	0.656	0.968	0.964	0.068	0.292	0.438	0.206	0.169	0.326
97	0.503	0.592	0.440	0.813	0.350	0.101	0.024	0.545	0.164	0.594
98	0.144	0.105	0.480	0.223	0.590	0.852	0.509	0.094	0.468	0.026
99	0.363	0.445	0.127	0.160	0.146	0.062	0.461	0.720	0.548	0.344
100	0.673	0.737	0.935	0.049	0.901	1.001	0.687	0.285	0.997	0.872

6.0 Straight Random Sampling Procedures Using Random Numbers

6.1 Sampling from a Belt or Flowing Stream of Material:

Determine an amount of production time to be considered a lot and the number of samples (n). Pick n random numbers to determine the times (t) to take the samples.

Example: the lot size is a 10-hour day (600 minutes) and three samples are needed. The random numbers 0.324, 0.612, 0.032 are chosen to represent the sublots. Drop the decimal point from the random numbers and the sampling times are 32 minutes and 324 minutes. The third number (.612) is dropped because it exceeds the lot time. A new number should be picked. AASHTO allows the actual time to be rounded off to the nearest five (5) minutes.

6.2 Sampling from a Windrow of Material:

Determine the length (L) of one windrow that represents a lot of material. Also, determine how many samples (n) will be needed. Select n random numbers from the table. Multiply these numbers by L to obtain sample locations.

6.3 Sampling from a Loaded Truck:

Determine how many trucks consist of a lot and how many samples (n) will be taken. Pick (n) numbers from the random number table to determine which trucks to sample from. Multiply these numbers by the number of trucks in the lot. Determine the quadrant in each truck to be sampled by choosing n random numbers and multiplying by four (4). Figure 1 shows the quadrant locations of the truck.

Example: A lot consists of 15 trucks and three samples will be taken from each lot.

(1) Pick three random numbers. In this case, we have chosen the following numbers: 0.251, 0.424, 0.865

(2) Trucks numbered 4 (.251*15), 6 (.424*15), and 13 (.865*15) will be sampled.

(3) Determine the quadrant locations. The following three numbers were chosen: 0.110, 0.380, 0.064

(4) Multiply the numbers by 4. From Truck 4, take a sample in quadrant 4 (.110*4=.44). From Truck 6, take a sample in quadrant 1 (.380*4=1.52). From Truck 13, take the sample in quadrant 2 (.064*4=.256).

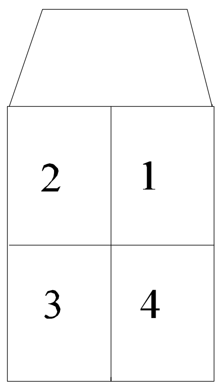


Figure 1.
Quadrant Locations

6.4 Sampling In-Place Paving Material:

Determine the length (L) of the lot, width (w) of the pavement, and the number of samples needed for each lot. Following the procedure for picking random numbers, pick L random numbers corresponding to length of pavement. Then, pick w random numbers for width determination. Sampling locations are then determined by multiplying the random numbers by the actual length (L) and width (w) of the lot.

Example: The lot is defined as 3.2 km and the pavement is 3.6 m wide. Two samples are needed from each lot. There are 3219 m in the lot.

(1) Enter the random number table and pick two numbers which will be multiplied by 3219.

(2) In this instance, 0.376 and 0.529 are chosen from the table. The two samples will be taken 1210 m and 1702 m from the beginning of the pavement.

(3) Select two more numbers to determine locations from the edge of the pavement. These numbers will be multiplied by 3.6.

(4) In this instance, 0.512 and 0.708 were selected. The two samples will be taken 1.8 m and 2 m from the edge of pavement.

(5) The first sample will be taken 1210 m from the beginning and 1.8m from the designated (right or left) edge of pavement. The second sample will be at 1702 m and 2 m.

6.5 Sampling from a Stockpile

AASHTO does not recommend the sampling of stockpiles. Stockpiles are prone to segregation and samples may not be representative of the material. Some agencies do use this procedure for determining sample locations in stockpiles.

Sample Test

True or False

1. A technician picks a number from the random number table to determine row number. The number was 0.792, which corresponds to row number 79.
2. AASHTO and ASTM do not recommend sampling from stockpiles.
3. When sampling loaded trucks, determine which trucks to sample by picking n random numbers from the table and multiplying these n numbers by the total number of trucks in the lot.
4. When sampling loaded trucks, additional random numbers need to be drawn for each sample in order to determine the quadrant of the truck to be sampled.
5. Straight random sampling procedures are identical to stratified random sampling procedures.
6. A technician picks a random number to determine column number. The number was 0.249, which corresponds to column number 9
7. Random numbers drawn are final; no matter what the situation they must be used or the random method will be jeopardized.
8. When sampling from a flowing stream of material, determine the total lot size by metric tons (t) and determine the number of samples needed. Random numbers represent the tonnage directly.
9. Stratified random sampling procedures mean that the sublot is divided into four sublots, which may or may not be equal.

Density of Soil In-Place by the Sand Cone Method

AASHTO T 191

1.0 Scope

The Sand-Cone Method determines the in-place density of soils. Density is important for determining a soil's level of compaction. Overall compaction is measured in relation to the laboratory moisture density test, which measures the maximum density of soil. In-place density is expressed as a percentage of the maximum laboratory dry density.

2.0 Apparatus

Density Apparatus: "shall consist of a 4 L jar and a detachable appliance consisting of a cylindrical valve with an orifice 12.7 mm in diameter and having a small funnel continuing to a standard G mason jar top on one end and a large funnel on the other end. The valve shall have stops to prevent rotating the valve past the completely open or completely closed positions" (AASHTO T 191, 2.1).

Sand: Use a clean, not-cementatious sand with few or no particles passing the 0.075 mm sieve, and none retained on the 2.00 mm sieve. AASHTO T 191 requires the bulk density of the sand to be measured several times to ensure that the sand does not have a variation in bulk density greater than 1 percent.

Balance: Conforming to AASHTO M 231, Class G20 (over 5 kg through 20 kg principle sample mass, sensitivity of 5 g or 0.1%); and conforming to AASHTO M 231, Class G2 (2 kg or less, sensitivity of 0.1 g or 0.1%).

Drying Equipment: A hot plate or sterno stove in the field suitable for drying moisture content samples.

Miscellaneous Equipment: Digging tools for test hole (small pick, chisels, spoons, scoops, etc.), suitable container for drying moisture sample (small pan), bucket or canvas bags to retain density sample, cache of density sand, thermometer for water temperature determination, brush for fines.

3.0 Equipment Preparation

Determining the bulk density of the sand (W_1) to be used in the test

1. Place the empty apparatus upright on a firm, level surface, close the valve, and fill the funnel with sand to determine the mass of the sandcone apparatus without sand in grams.
2. Open the valve and, keeping the funnel at least half full of sand, fill the apparatus. Close the valve sharply and empty excess sand.
3. Weigh the apparatus with the sand and determine the net mass of sand by subtracting the mass of the apparatus.
4. Calculate the bulk density of the sand as follows:

$$\mathbf{W_1} = \frac{W_2}{V_1}$$

W_1 = bulk density of the sand in grams per cubic centimeter

W_2 = grams of sand required to fill the apparatus

V_1 = volume of the apparatus in cubic centimeters

Remember to avoid any vibration of the sand during the mass/volume calculation. Vibration could cause the bulk density of the sand to be higher than normal.

Check the bulk density of the sand regularly. Slight changes in moisture or degradation of the sand during the storage and transport may affect the sand density determination. It is also acceptable to determine the bulk density of the sand using other volumetric containers, provided that the bulk density as determined by these other methods is shown to be equal to the bulk density of the sand as determined by the sand cone.

Determining the mass of the sand required to fill the cone

1. Put sand into the apparatus and close the valve.
2. Invert the apparatus on a clean, level surface so that the cone is facing down. If a base plate is used normally during testing then it must be used during the calibration process as well.
3. Open the valve and allow the sand to flow until its stops. Close the valve sharply and weigh the apparatus with the remaining sand in the jar. Determine the loss of sand and record it as the weight of sand required to fill the cone.
4. Replace the sand used for this determination and close the valve. The sand cone is now ready and calibrated for use.

When testing soils that will not permit a uniform and level testing area, AASHTO T 191 Note 7 recommends measuring the mass of sand required to fill the cone and the unbounded testing surface in lieu of measuring just the sand required to fill the cone. This is a special situation and is used to compensate for sand loss to uneven surfaces.

4.0 Procedure

1. Make sure the jar is filled with enough sand to fill the hole volume and the cone. Weigh the apparatus with sand prior to use. This mass will be used to determine a loss of sand after it has been used to fill the excavated hole and cone.
2. Prepare the surface of the location to be tested so that it is a level plane.
3. Seat the inverted apparatus on the prepared plane surface and mark the outline of the funnel. Alternately, place the base plate on the level surface.
4. Step 4 is not listed in AASHTO T 191; it is adopted from ASTM D 1556-90. Remove the soil from the area outlined by the cone or within the area bounded by the base plate hole. Take care not to disturb the soil that will bound the hole while removing the soil from the volume of the test hole. The volume of the hole is dependent upon maximum particle size of the material being tested in conformance to AASHTO T 191, Table 1. A larger jar and cone may be needed when the volume exceeds 0.1 cubic feet.

   "The walls of the hole should slope slightly inward and the bottom should be reasonably flat or concave. The hole should be kept as free as possible of pockets, overhangs, and sharp obtrusions since these affect the accuracy of the test. Soils that are essentially granular require extreme care and may require digging a conical shaped test hole. Place all excavated soil, and any soil loosened during digging, in a moisture tight container that is marked to identify the test number. Take care to avoid loss of any materials. Protect this material from any loss of moisture until the mass has been determined and a specimen has been obtained for a water content determination" (ASTM D 1556, 7.1.5).