

DENSITY TESTING AND INSPECTION MANUAL

2024 EDITION



**CONSTRUCTION FIELD SERVICES
DIVISION**

FOREWORD

This manual provides guidance to administrative, engineering, and technical staff. Engineering practice requires that professionals use a combination of technical skills and judgment in decision making. Engineering judgment is necessary to allow decisions to account for unique site-specific conditions and considerations to provide high quality products, within budget, and to protect the public health, safety, and welfare. This manual provides the general operational guidelines; however, it is understood that adaptation, adjustments, and deviations are sometimes necessary. Innovation is a key foundational element to advance the state of engineering practice and develop more effective and efficient engineering solutions and materials. As such, it is essential that our engineering manuals provide a vehicle to promote, pilot, or implement technologies or practices that provide efficiencies and quality products, while maintaining the safety, health, and welfare of the public. It is expected when making significant or impactful deviations from the technical information from these guidance materials, that reasonable consultations with experts, technical committees, and/or policy setting bodies occur prior to actions within the timeframes allowed. It is also expected that these consultations will eliminate any potential conflicts of interest, perceived or otherwise. MDOT Leadership is committed to a culture of innovation to optimize engineering solutions.

The National Society of Professional Engineers Code of Ethics for Engineering is founded on six fundamental canons. Those canons are provided below.

Engineers, in the fulfillment of their professional duties, shall:

1. Hold paramount the safety, health, and welfare of the public.
2. Perform Services only in areas of their competence.
3. Issue public statement only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honorably, reasonably, ethically and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

This manual has been prepared to document procedures used by the Michigan Department of Transportation (MDOT) to assure quality in density testing and inspection in the field. It reflects current Michigan Department of Transportation practice, as based on past experience and on recognized national standards in testing procedures. This manual is written to serve as a procedures manual and training aid for technicians performing density testing on MDOT projects. Technician qualification requirements are documented in accordance with 23 CFR 637. Furthermore, this manual is part of MDOT's Materials Quality Assurance Program.

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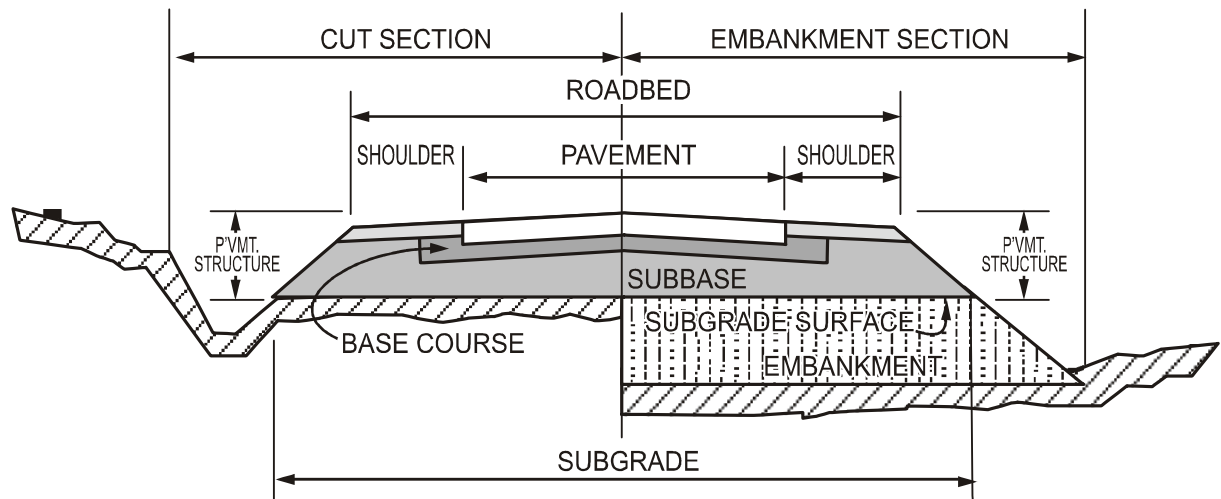
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Road Section Nomenclature

I. DENSITY TESTS AND METHODS

A. Introduction

1. SOILS

Soil is a natural body occupying the portion of the earth mainly composed of mineral and organic materials and, unless otherwise specified, may include any unconsolidated deposit down to hard rock. Soils, as found in the field, are mixtures of soil particles, air and water. The soil particles are classified as clay, silt and sand and these are called soil separates. Clay is the finest grain size, silt is the next finer and sand is the most coarse.

Texture classes are also called clay, silt and sand. They are so classified because they carry the predominant characteristics of the soil separate name they are identified with. A clay soil is very sticky when wet and lumpy when dry. It has strong cohesion (attraction between particles) and is commonly called a cohesive soil. Clay soils have relatively high natural moisture contents. Silt is floury in appearance, has a talcum powder “feel” and a great affinity for retaining water. Sand is a non-cohesive soil which is not sticky when wet and very loose and fluffy when dry. The natural moisture content of sand is relatively low as compared with clay.

Soil mixtures may also contain some amounts of gravel, which is a granular material. By AASHTO definition gravel will pass the 3-inch sieve and be retained on the No. 10 sieve. Cobbles and boulders are larger rocks which may also be present in soils.

For the purpose of this manual, the term “soil” refers to mixtures of soil, air and water. The terms clay, silt and sand refer to their textural class.

2. HOT MIX ASPHALT (HMA) MIXTURES

HMA mixtures are hot plant-manufactured materials. The mixtures consist of predetermined amounts of sand, stone, fines and bitumen. The mixtures could also consist of various amounts of recycled materials.

Delivered to the job site, the HMA mixtures are placed in layers and are normally used as bases, binders, leveling and top courses.

3. STABILIZED MIXTURES

Stabilized mixtures consist of any existing material which is retextured or mixed with a stabilizing agent.

The most common method of stabilization consists of mixing hot bitumen with an existing mixture of ground-up HMA surface and aggregate base. The layer of stabilized material is then used as a base course for a new HMA surface. Stabilization increases the bearing capacity and stability of the existing material and reduces reflective crack patterns normally associated with resurfacing projects.

4. PULVERIZED PAVEMENT MIXTURES

Pulverized pavement mixtures consist of existing HMA and/or concrete surfaces, pulverized and mixed with some portion of the underlying aggregate base.

The resulting mixture of pulverized HMA or concrete and aggregate base material is then compacted and used as a base course for new or recycled pavement surfaces. This is another method of recycling existing HMA and concrete surfaces by utilizing existing material and increasing the load carrying capacity of the resulting new pavement.

5. DENSITY

Density is a ratio expressed by the formula $D=W/V$ or density equals the weight of material divided by the volume it occupies. A simple example is the density of water. Each cubic foot of water weighs 62.4 pounds; thus, the density of water is 62.4 pounds per cubic foot. In soil testing, density is used to determine the degree of compaction by comparing the In-Place Density to the Maximum Density. The degree of compaction, expressed as a percent, is then compared to the specification requirement to determine pass or fail. Maximum Density is a standard expressed in pounds per cubic foot which is arrived at by applying a standard compactive effort to a soil mixture under controlled conditions.

6. COMPACTION

Compaction is the elimination of excess air spaces (voids) in a soil by mechanical means. Vibration is a good mechanical means in sand soils; compression and impact are more successful means of compaction in clay soil. Some common types of equipment used for compaction on sand are track-type dozers, vibrating rollers, wobble-wheel rollers and plate-type vibrators. Common types of equipment used on clay are sheepfoot rollers, rubber-tired rollers and rubber-tired hauling equipment. To obtain a desired amount of compaction, it may be necessary to lower or raise the moisture content in the soil.

Compaction of HMA mixtures is accomplished by the rearrangement of the particles to reduce the amount of voids to a predetermined percentage of the compacted mass. Asphalt binder is a thermoplastic liquid and as a lubricant in the arrangement of the particles, its temperature is critical. Compaction of the HMA mixture must be obtained while the asphalt binder is still hot and fluid.

Compaction of HMA mixtures is normally obtained in four stages: paver screed effort, breakdown rolling effort, intermediate and clean up rolling effort. Rollers presently allowed are rubber-tired, steel-wheeled vibratory and static rollers.

7. THE DENSITY TEST

The Michigan Department of Transportation currently uses four main tests to control the compaction of soils, HMA mixtures and recycled mixtures: the One-Point T-99 (Proctor) Test, the One-Point Michigan Cone Test, the Michigan Modified T-180 Test and the Density In-Place (nuclear) Test. The AASHTO T-99 Test and the Michigan Cone Test are only used as referee tests and typically performed in a lab setting.

The One-Point T-99, One-Point Michigan Cone and Michigan Modified T-180 Tests are used to determine Maximum Density of soil and recycled materials. The One-Point T-99

and One-Point Michigan Cone Tests are departmental adaptations of the AASHTO T-99 and Michigan Cone Tests. The nuclear gauge is used to check density of material In-Place. The One-Point T-99 Test is used for cohesive soils such as clay and all other soils having a loss-by-washing of more than 15 percent. The One-Point Michigan Cone Test is used for sand and gravel having a loss-by-washing of 15 percent or less, including aggregate base courses and Granular Material Classes I, II and III. The Modified T-180 Test is used on materials that are stabilized In-Place, pulverized HMA and crushed concrete. These terms are defined in the appendix of this manual.

TESTS TO DETERMINE MAXIMUM DENSITY

Material	Test
Granular materials having 15% or less loss-by-washing. This includes 23 A and 23AA which can have up to 16%.	One Point Michigan Cone Test
Slag Aggregate material	One Point Michigan Cone Test
Cohesive materials having more than 15% loss-by-washing	One Point T-99 Test
Pulverized HMA used as Aggregate Base Course	Michigan Modified T-180 Test
Crushed concrete used as Aggregate Base Course	Michigan Modified T-180 Test
Stabilized in-place materials	Michigan Modified T-180 Test

8. CONTROLLED DENSITY METHOD

a. DESCRIPTION

The Controlled Density Method is the standard procedure used by the Michigan Department of Transportation to control the placement and compaction of embankment and backfill material.

Material is placed in horizontal layers not exceeding a thickness of 9 inches for clay/cohesive soil or 15 inches for granular soil. The loose soil layer must be compacted by mechanical means to the minimum specified density. Each layer is tested and accepted before the succeeding layer is started. The equipment used to spread the material and the type of equipment used to compact the material is determined by the contractor. The primary requirement is that the material be placed in discreet horizontal layers and uniformly compacted to the specified density throughout the fill area.

Where tests indicate inadequate density, it is generally due to one of two reasons:

- 1) Improper moisture content
- 2) Insufficient compactive effort

b. MOISTURE CONTENT

Improper moisture content is the greatest single cause of difficulty in attaining the specified density requirement, especially for cohesive soil. MDOT specifications require that cohesive soils have moisture content not greater than 3 percent above optimum at the time of compaction, except for the top 3 feet of embankment which must not exceed optimum. If the material contains excessive moisture, it must be aerated and dried by disking or other effective methods before being compacted. The succeeding layer must not be placed until the specification requirement is met. Sometimes, where large areas of embankment are to be constructed, a layer of wet material may be left to dry while placing or compacting operations are alternately being performed at another embankment area. Because the natural moisture content of clay soil is often near optimum or above optimum, the addition of water is generally not required. However, if the material is dryer than optimum, water may need to be added to facilitate compaction.

The closer the moisture content is to optimum, the easier it is for the contractor to attain density. At times, where the cut material is composed of both wet and dry material, grading operations may require some mixing after the material is deposited on the grade and before compacting. Although it is generally not economically practical for the contractor, he may elect to waste the wet material and replace it with an equal volume of drier material. When atmospheric conditions permit little or no evaporation, wet material cannot be manipulated, aerated and dried. During such periods, which generally include later fall, winter and early spring, the contractor often chooses to wait for more favorable construction weather.

The compaction characteristics of sand soils are much less sensitive to moisture variation and can be satisfactorily compacted over a wide range of moisture content. In as much as the natural moisture of sand soils is often in a bulking range of 3 to 5 percent, compaction is often attained more quickly and with less effort by adding water. Excessive moisture is generally not a problem with sand, except for saturated fine sand which has been excavated from below the water table. In this case, the usual solution is to allow the material time to dry until the moisture content is less than optimum before placement and compaction are attempted. The succeeding layer must not be placed until the specification requirement is met. Further, all backfill must be at or below optimum moisture before placing additional material. The compaction of granular material can generally be conducted in wet weather and sometimes even in freezing weather.

At times, the soil of the original ground contains enough moisture to become spongy when trying to place the first layer of an embankment, making compaction almost impossible. If this spongy condition is not corrected, the embankment will usually continue to be spongy with each succeeding layer. Sometimes it is possible to remedy this problem by disking and aerating the original ground. If the original ground contains an excess of moisture so that manipulation is not practical, it may be necessary to

construct the first layer of Granular Material Class III to the minimum elevation at which the equipment can be operated.

When the moisture of the embankment material is at or near optimum, the contractor should have little difficulty in obtaining satisfactory density if adequate compactive effort is applied. When heavy earthmoving equipment places the material in thin layers over a large area, and if the units break track for maximum compactive coverage, they can usually attain satisfactory compaction alone. A common problem occurs when many units are hauling a short distance to a small embankment area. To obtain uniform compaction, supplemental compaction equipment must be added.

c. PLACEMENT AND COMPACTION OF MATERIAL

Whenever density tests indicate that the contractor has not obtained the specified density, he must be directed that the succeeding layer must not be placed until the specification requirement is met. The decision as to how the corrective work is to be done is left up to the contractor. From the test results and from observation, however, the inspector should recognize the reason for the low density and could suggest appropriate action such as disking the wet soil to dry it, adding water to a dry soil, or simply doing more rolling if moisture is not the problem.

While specifications permit the placement of clay in layers up to 9 inches thick and sand in layers up to 15 inches, better results are obtained if the material is spread and compacted in thin layers. Layers 3 to 5 inches thick require less compactive effort and promote better hauling conditions.

Heavy earthmoving equipment generally causes some “kneading” or movement of a compacted clay fill under passing wheel loads even though the soil is at Optimum Moisture. In all but dry cohesive soils a moderate amount of such movement is to be expected and is not detrimental. In general, the surface should rebound after the wheel passes and should not leave a rut more than 1 to 3 inches deep. Occasionally, some sensitive clays are observed to rut deeply even though the density and moisture requirements are within specification. When such actions are observed, density test computations, procedures and equipment should be reviewed to confirm that specification requirements are being met. The Area Density Specialist should participate in this review. If the condition continues up to subgrade elevation, it is suggested that the Delivery Engineer consult with the Region Soils Engineer to determine whether disking and drying should be performed to ensure a more firm subgrade.

Although the type of compaction equipment used is left entirely to the option of the contractor, experience has shown that certain equipment is more efficient for compacting one type of soil than another. A sheepsfoot roller, for example, is generally more effective in compacting clay than sand.

Vibratory equipment is effective on granular soils and relatively inefficient for compacting clay. Heavy, multi-wheel, pneumatic rollers are effective for all types of soils. Small plate vibrators are generally more efficient than tampers for compacting granular trench backfill.

For many types of soil, the very top 2 inches or so of the layer being compacted remains loose until it has been confined by placement of the succeeding layer. For that reason, it is important that the loose surface be scraped away before the density test is taken.

Special problems and consideration arise when soil is placed and compacted during freezing weather. Winter construction is covered under “Winter Grading” in the MDOT Construction Manual.

9. EQUIPMENT

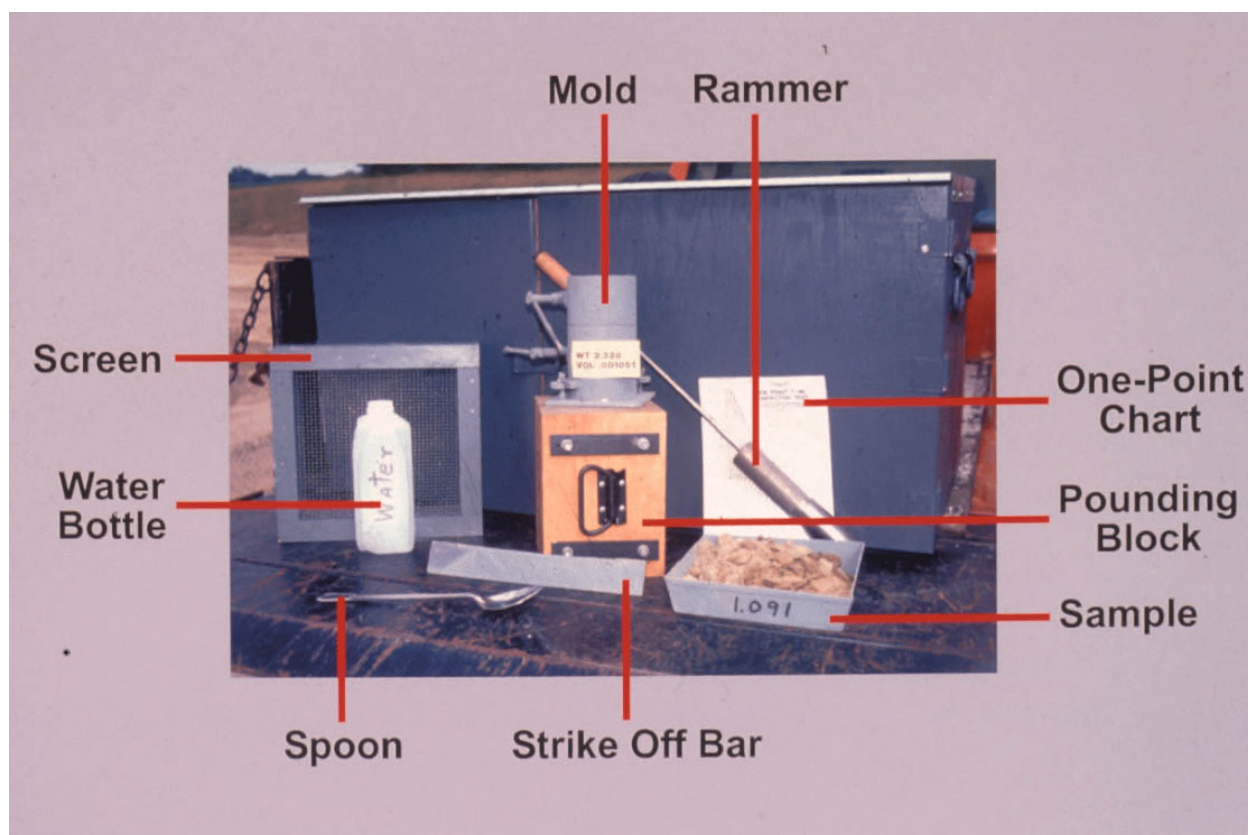


Figure 1. One-Point T-99 Test and AASHTO T-99 Test

Figure 1 shows the equipment used for the One-Point T-99 and the AASHTO T-99 Tests. It consists of a cylindrical mold (Proctor mold) 4 inches in diameter with a detachable collar and base plate, a 5.5-pound rammer (or hammer device) with a 12 inch drop, a strike-off bar, a hardwood pounding block, a $\frac{1}{4}$ inch mesh screen mounted on a wood frame and a water bottle.

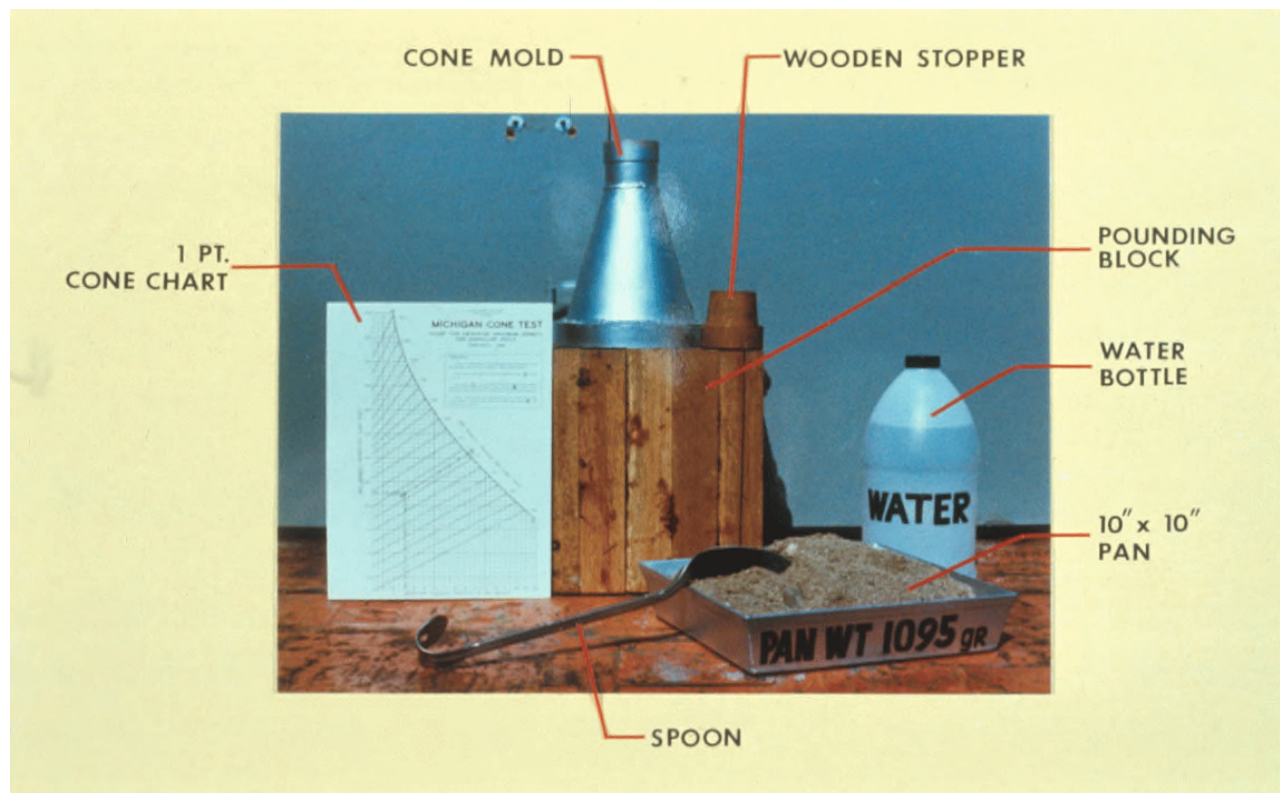


Figure 2. One-Point Michigan Cone Test and Michigan Cone Test

The equipment used for the One-Point Michigan Cone Test and Michigan Cone Test is shown in Figure 2 and consists of an inverted funnel mold commonly referred to as a “cone” having a solid bottom at the larger end, a hardwood pounding block and a water bottle.

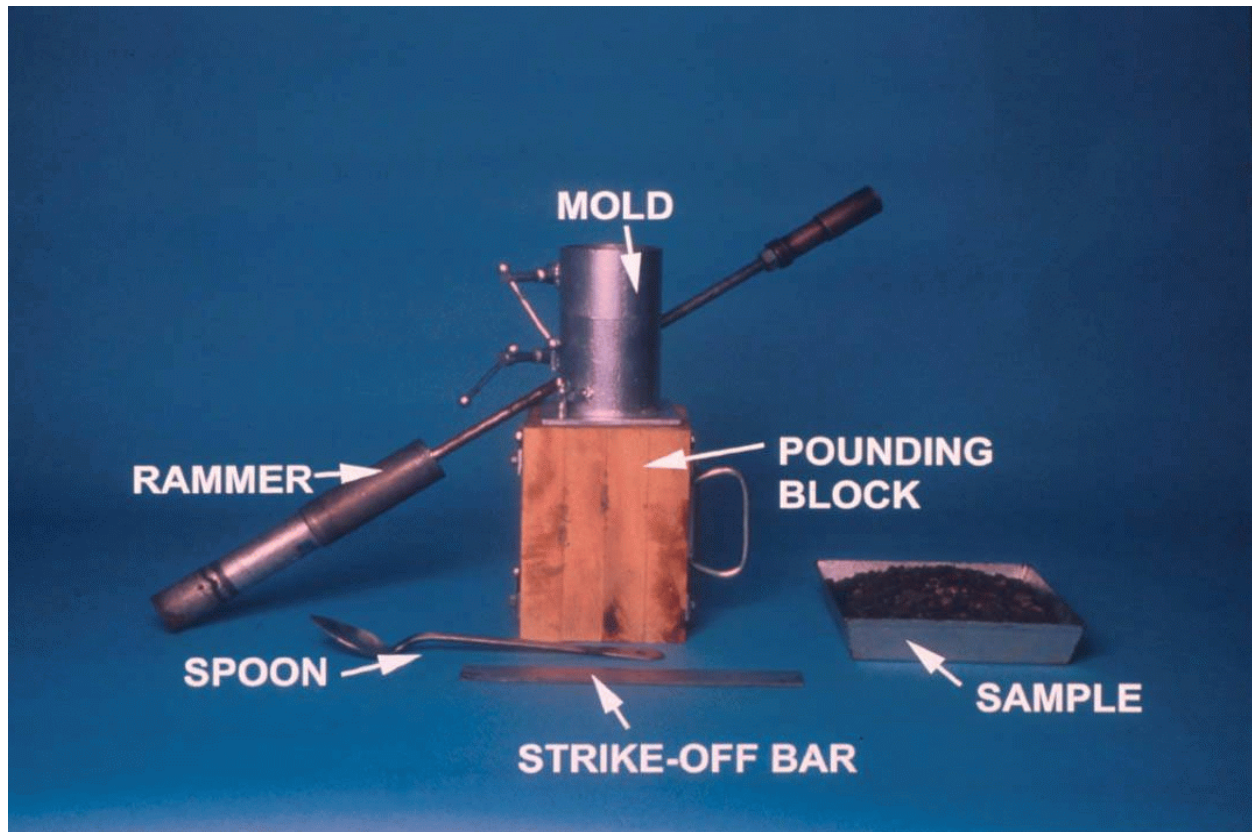


Figure 3. Michigan Modified T-180 Test

The equipment used for the Michigan Modified T-180 Test is shown in Figure 3 and consists of the following: a hardwood pounding block, a cylindrical mold (Proctor mold) 4 inches in diameter, 10-pound rammer with an 18 inch drop and strike-off bar.

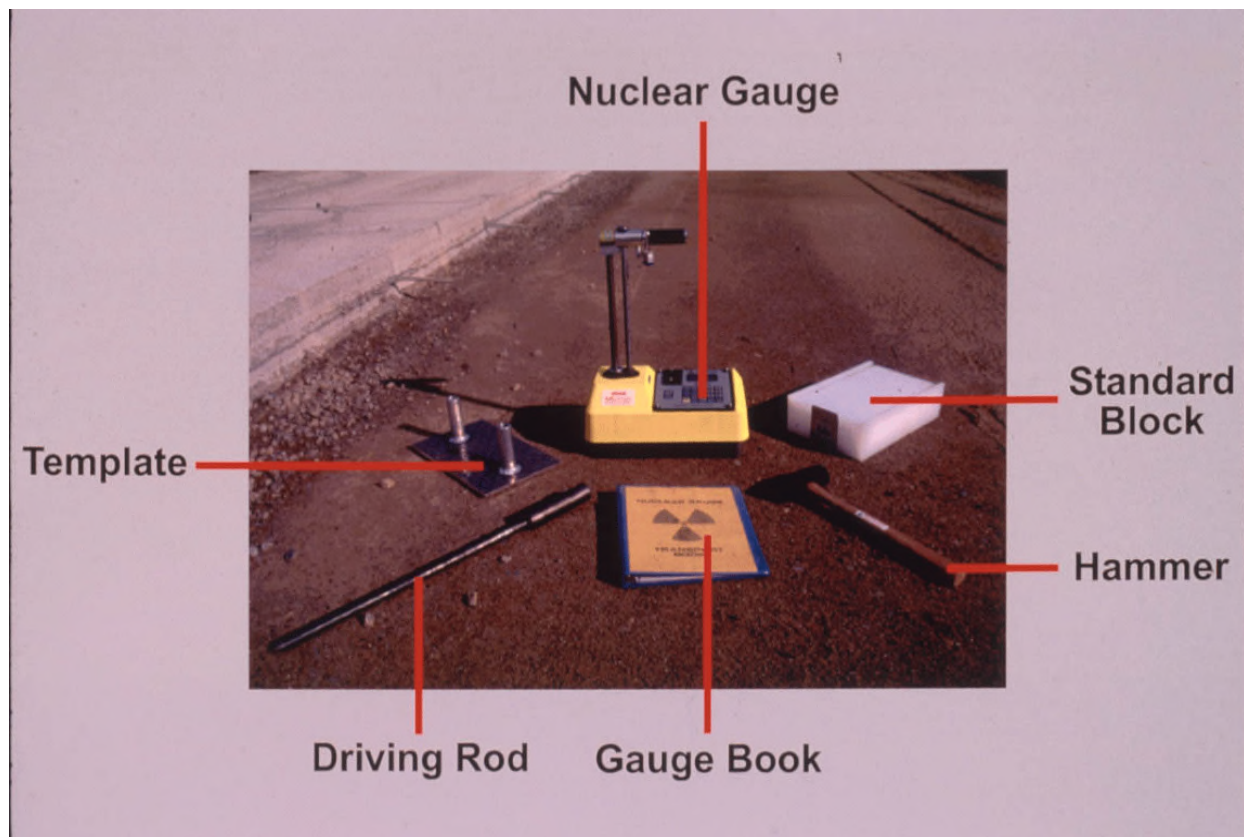


Figure 4. Nuclear Density In-Place Test

The density of material In-Place is determined by the use of a Nuclear Moisture Density Gauge (Figure 4). The Michigan Department of Transportation currently permits the use of the Troxler model 3400 series, the InstronTek Xplorer model 3500, and the CPN Elite series gauges. Other equipment used in this test includes a gauge book, standard block, template, drill rod and hammer.

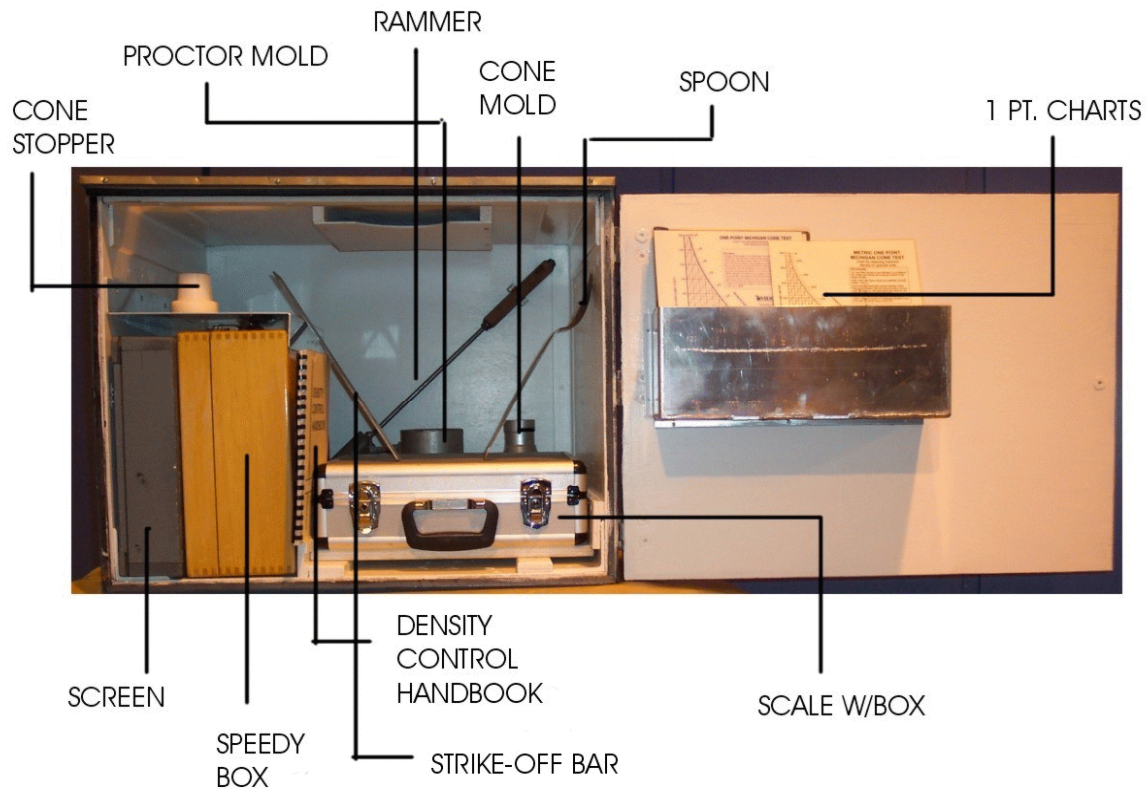


Figure 5. Contents of an MDOT density box

A typical density box and detailed views of equipment contained in the MDOT truck-mounted density box are shown in Figure 5.

Figures 6a and 6b show a nuclear density gauge secured in the MDOT Type A Box and in the manufacturer's carrying case housed in the NUX Safety Containment Box, respectively.



Figure 6a. Troxler nuclear gauge secured in the MDOT Type A box in a cab of a pickup truck.



Figure 6b. Troxler nuclear gauge secured in the manufacturer's carrying case housed in the NUX Safety Containment Box.

10. PERSONAL PROTECTIVE EQUIPMENT (PPE)

When conducting density inspection and testing always abide by MDOT's policy for personal protective equipment. For complete details as to the requirements contained in this policy refer to MDOT Guidance Document # 10118. As a minimum, the following PPE must be worn at all times when conducting density testing:

- hard hat
- safety glasses
- safety vest
- safety toe footwear

Additional PPE may be necessary depending on the specific test performed and may include:

- hearing protection
- hand protection

B. DENSITY TESTS

1. THE ONE-POINT T-99 TEST

a. DESCRIPTION

A Michigan adaptation of the AASHTO T-99 (Method C, Modified) Test is the “One-Point T-99 Test.” The modification to the AASHTO test procedure is described in the Michigan Test Method (MTM) 404. The equipment used and the procedures for compacting the mold are the same as in the full AASHTO T-99 Test plus a One-Point T-99 Chart. The test name is derived from the fact that only one mold needs to be completed. In Michigan, it is the primary test used to determine the Maximum Density of soils having a loss-by-washing greater than 15 percent.

Figure 1 shows the equipment used for the One-Point T-99 Test. It consists of a cylindrical mold (Proctor mold) approximately 4 inches in diameter with a detachable collar and base plate; a 5.5-pound rammer or hammer device with a 12 inch drop; a sharp-edge strike-off bar; a hardwood pounding block; a $\frac{1}{4}$ inch mesh screen mounted on a wood frame; and a water bottle. The equipment shall be calibrated/checked annually.

b. PREPARING AND COMPACTING THE SAMPLE

A representative sample, approximately 3500 grams, is taken from the In-Place Density test site. This sample should be thoroughly broken up by running it through the screen as shown in Figure 7. The coarse material retained on the screen is then visually inspected. Stones estimated to be larger than 1 inch are removed and replaced with an equivalent weight of smaller stone. The replacement stone must be less than 1 inch but still large enough to be retained on the screen. This process must be completed as quickly as possible to avoid loss of moisture through evaporation. The stones retained on the screen are now added back to the sample.



Figure 7. Typical sample of approximately 3500 grams of soil after screening

The test must be started with the soil moisture content within a range from optimum to 4.0 percent below optimum. The closer to optimum the moisture content, the more accurate the test will be. With experience, the inspector can determine this by the texture, consistency and appearance of the soil. It may also be determined by a simple hand cast test. Take a handful of the sample and squeeze it tightly in your fist to form a soil cast. If the moisture content is within the desired range, the cast will hold together firmly as shown in Figure 8 (left). Significant effort is required to break the cast as shown in the right half of Figure 8. If the sample is too dry, the cast will not form or will crumble easily when disturbed. If the sample is dry, more water should be added before the test is started. When water is added, the sample should be thoroughly mixed and run through the screen a second time. If the sample is too wet, the cast will mold very easily and may even feel sticky. The sample should then be dried by running it through the screen and spreading it out on top of the density box. This is particularly effective in hot weather. If the moisture content of the sample was determined by the hand cast method to be within the appropriate range, from optimum to 4.0 percent below optimum, then the Moisture % from the In-Place Density Test is recorded in Column B on Form 0582B (Figure 11). If the moisture content of the sample was adjusted before the mold was compacted, then the moisture content must be determined using the "Speedy" moisture tester after completing the One-Point T-99. Refer to page 56 for instructions on the use of the "Speedy." Record the Moisture % in Column B. Place a circled "S" in the box to indicate that the Moisture % was determined by the "Speedy" moisture tester.



Figure 8. Appearance of the soil cast between 4.0 percent below Optimum Moisture and Optimum Moisture (left), broken up under hand pressure (right)

The Proctor mold is then assembled and placed on a hardwood block (Figure 9), supported on firm ground or existing pavement, but not on the tailgate of a pickup truck. A layer of soil is placed in the mold in quantity sufficient to fill one-third of its volume after compaction. The soil is then compacted in the mold by 25 blows of a 5.5-pound rammer weight, dropping 12 inches as shown in Figure 9. While compacting the soil, the rammer should be moved about the soil surface in the mold to obtain uniform compaction of each layer. It is important that the rod be held vertical and the rammer weight dropped freely since it is a standard compactive effort. Any increase or decrease in the effort may materially affect the accuracy of the test. A second layer of soil is

added, filling another one-third of the volume of the mold after compaction. This, too, is compacted by 25 evenly distributed blows. The third and final layer is then added, including enough soil to extend slightly above the top of the mold, after compaction. The third layer is compacted by 25 evenly distributed rammer blows. After the collar has been removed, the compacted soil should extend $\frac{1}{4}$ to $\frac{1}{2}$ inch above the top of the mold as shown in Figure 10 (top). If the soil does not extend $\frac{1}{4}$ inch above the mold or if the soil extends more than $\frac{1}{2}$ inch above the mold, the test should be repeated.

The material is then struck-off even with the top of the mold using the strike-off bar, as shown in Figure 10 (bottom). If stones are encountered at this level, stones extending above the mold more than halfway are removed, stones extending less than halfway are driven in with the blunt edge of the strike-off bar. Any remaining voids should be filled with fine material.



Figure 9. Proctor mold resting on the wood block



Figure 10. After removing collar, compacted soil extending $\frac{1}{4}$ to $\frac{1}{2}$ inch above the top of mold (top) is removed with strike-off bar (bottom)

TEST NUMBER	MOISTURE %	VOLUME MOLD CU. FT.	DETERMINATION OF MAXIMUM DENSITY (SOIL & HMA)							NOTE: To convert (g) to (lbs.): Wt. (g) + 453.59 = Wt. (lbs.)
			WET SOIL + MOLD g	MOLD g	WET SOIL g	WET SOIL lbs	COMPACTED SOIL WET PCF	MAX DENSITY PCF	OPTIMUM MOISTURE %	
A	B	C	D	E	F	G	H	I	J	CHART STANDARDS
1	17.3	0.0363	4,454	2,495	1,959	4.32	119.0	103.4	19.6	DENSITY
										2,757
										2,702
										MOISTURE
										755
										725
										OPERATING STANDARDS
										DENSITY
										2,710
										MOISTURE
										736

Figure 11. Entries and computations for the One-Point T-99 Test

c. WEIGHING THE SAMPLE

Next, the base plate is removed and the mold and sample are weighed to the nearest gram (Figure 12). This weight is recorded in Column D (Wet Soil + Mold) on Form 0582B as shown in Figure 11. The volume of the mold and the weight of the mold when empty are painted on its side. The weight is recorded in Column E and the volume in Column C. The correct method of weighing is very important. When using a digital scale, be sure the scale is clean and level on a hard flat surface. Careless weighing procedures can cause significant differences in test results.



Figure 12. Weighing proctor mold and material on the scale provided in the density box

d. DETERMINING MAXIMUM DENSITY AND OPTIMUM MOISTURE

Complete the computations through Column H (Compacted Soil Wet) as shown in Figure 11. This is accomplished by subtracting the weight of the mold (Column E) from the weight of the material and mold (Column D). The result is recorded in Column F (Wet Soil). Convert the weight in grams (Column F) to pounds by dividing by 453.59 and record in Column G (Wet Soil, lbs.). The Compacted Soil Wet (Column H) is determined by dividing the Wet Soil (Column G) by the volume of the mold (Column C).

Maximum Density and Optimum Moisture are found by applying the Moisture % (Column B) and the Compacted Soil Wet (Column H) to the One-Point T-99 chart, shown in Figure 16. As an example, assume that the results from a One-Point Test are as follows: Compacted Soil Wet (Column H) or “Wet Density” is 119.0 pounds per cubic foot and the moisture content is 17.3 percent. Referring to figure 15, locate this moisture content on the horizontal leg (abscissa) and the Wet Density on the vertical leg (ordinate), and then project lines on the chart as indicated by dashed lines **1** and **2** to an intersection **A**. Next, project point **A** upwards and to the right, as indicated by dashed line **3** to an intersection **B** with the solid outside boundary line. This point of intersection **B** is the Maximum Dry Density, in this case 103.4 pounds per cubic foot.

To obtain Optimum Moisture, proceed downward vertically from point **B** as indicated by solid line **4** to intersect the horizontal leg (abscissa) at point **C**. The percentage shown at point **C** is the Optimum Moisture, in this case 19.6 percent.

Record the Maximum Density (Column I) and Optimum Moisture % (Column J) on Form 0582B as shown in Figure 11.

If point **A** falls to the right of the Maximum Density curve, the soil is too wet. The moisture content should be reduced by drying the sample and the test repeated.

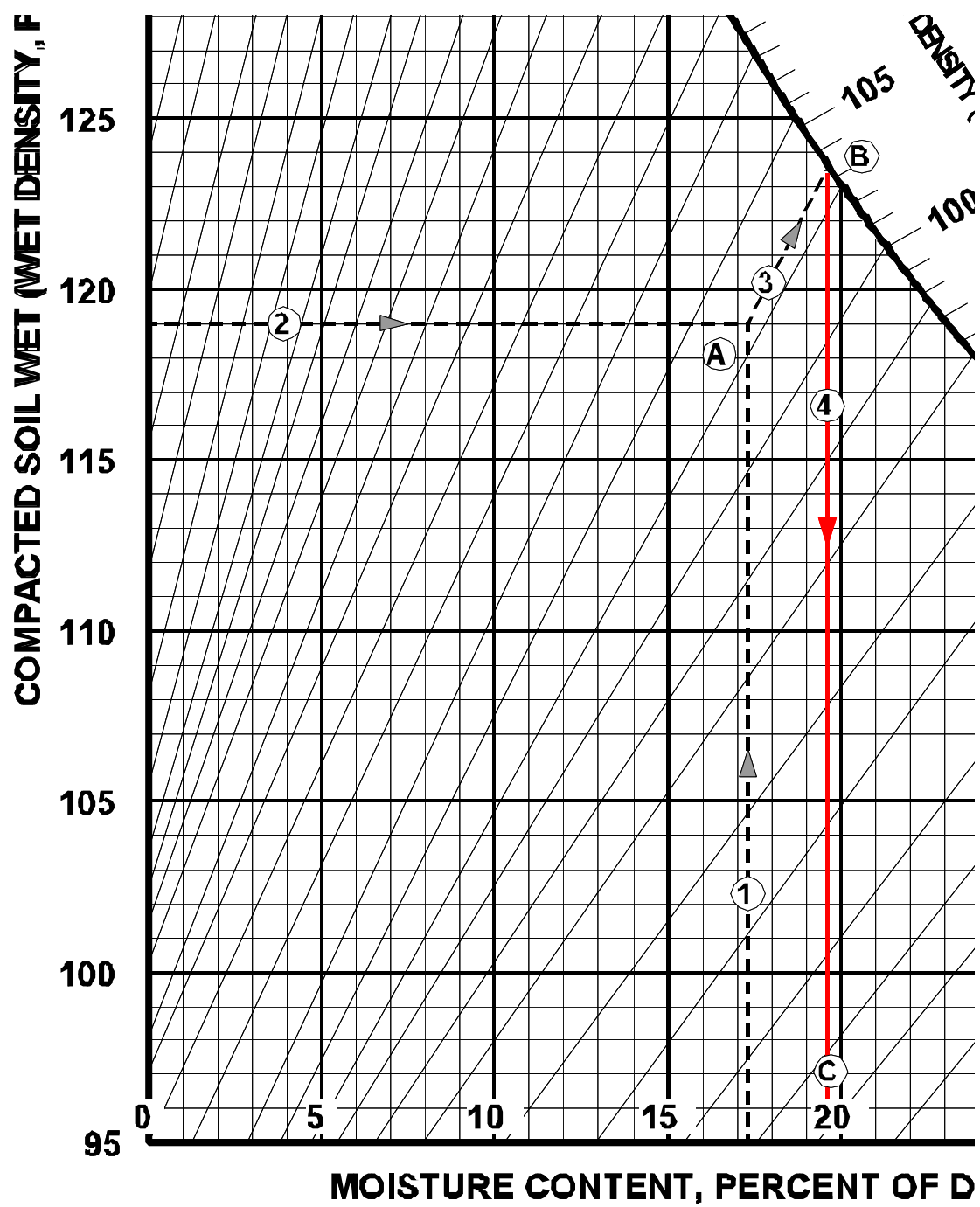


Figure 15. Steps 1, 2, 3 and 4

e. PRECAUTIONS IN PERFORMING THE ONE-POINT T-99 TEST

Experience has shown that the following items are important to keep in mind when performing the One-Point T-99 Test:

- 1) Establish a new Maximum Density any time the material changes (minimum of one per day) or the percent compaction exceeds 100.0.
- 2) Thoroughly break up the sample by running it through the screen before compacting it in the mold.
- 3) Pound within a moisture range from optimum to 4.0 percent below optimum. The closer to optimum the moisture content is, the more accurate the test will be.
- 4) Make sure the clamp on each mold section is tight.
- 5) Make sure the wing nuts on the base plate are secured with equal tension.
- 6) Place the mold on a solid block that is supported on firm soil or pavement.
- 7) Hold the rammer vertically so that it will fall freely.
- 8) Drop the 5.5-pound rammer weight freely for each 12 inch blow.
- 9) Use exactly 25 blows on each layer.
- 10) Place 3 equal layers in the mold.
- 11) Use enough material in the third layer so that when compacted, the material extends $\frac{1}{4}$ to $\frac{1}{2}$ inch above the top of the mold. If the third layer is not above the top of the mold, repeat the test.
- 12) When using the chart, use the Compacted Soil Wet (Column H) and Moisture % (Column B).
- 13) If the point on the chart obtained by plotting the Compacted Soil Wet and Moisture % falls to the right of the Maximum Density curve, the sample is above Optimum Moisture content. Dry the sample and repeat the test.
- 14) On Form 0582B, record the Maximum Density (Column I) and the Optimum Moisture % (Column J) obtained from the chart.
- 15) When making entries on Form 0582B, interpolate decimal fractions by using the grid lines on the chart.
- 16) Additional precautions for weighing and moisture sampling for this test and others are provided in the appendix.

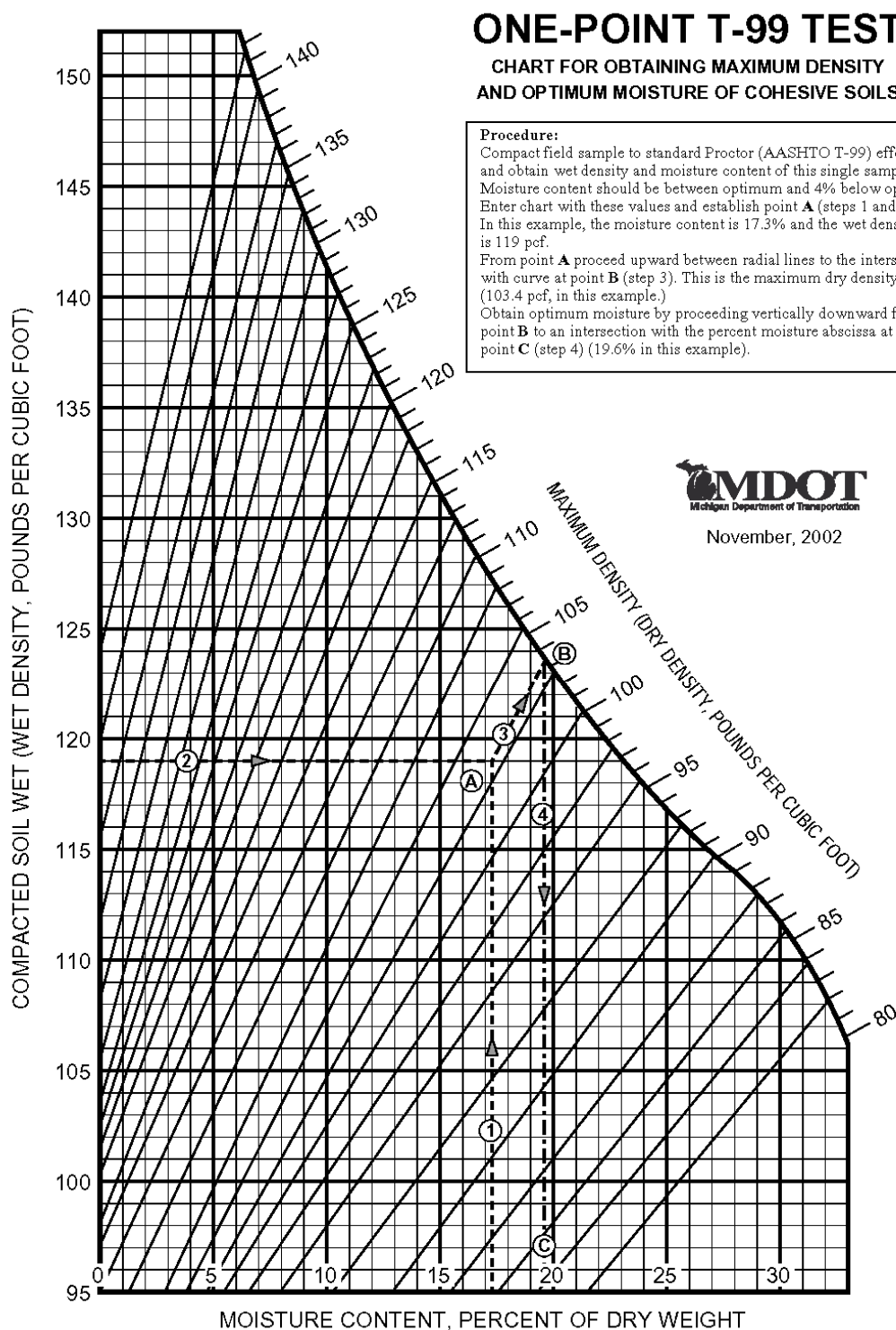

 Robert D. Miller, MDOT C & T Division
 November 22, 2002
 T99BLK.PDF

Figure 16. One-Point T-99 Chart

2. THE AASHTO T-99 TEST

a. DESCRIPTION

The department uses the AASHTO T-99 (Method C, Modified) test as a referee or supplemental test to the One-Point T-99 test to determine the Maximum Density of soils having a loss-by-washing greater than 15 percent. It is usually performed in a lab setting and used by the inspector at the direction of the Area Density Specialist. The equipment used is the same as that used for the One-Point T-99 Test (Figure 1) except for the One-Point Chart. The equipment shall be calibrated/checked annually.

b. PREPARING AND COMPACTING THE SAMPLE

A representative sample, approximately 5000 grams, is taken from the soil to be tested.

This sample should be thoroughly broken up by running it through the screen as shown in Figure 7. The coarse material retained on the screen is then visually inspected. Stones estimated to be larger than 1 inch are removed and replaced with an equivalent weight of smaller stone. The replacement stone must be less than 1 inch but still large enough to be retained on the screen. This process must be completed as quickly as possible to avoid loss of moisture through evaporation. The coarse material retained on the screen is now added back to the sample.

The test should be started with the soil having a moisture content approximately 4.0 percent below optimum, which is determined by the hand cast. Figure 17 (left) shows a cast of soil having approximately this moisture content. At 4.0 percent below optimum, the cast will barely hold together, is readily friable, and will break easily with minimal hand pressure as shown in Figure 17 (right). It may be necessary to either add water or to dry the sample to obtain the desired moisture content. When water is added, the sample should be thoroughly mixed and run through the screen a second time. If the sample is too wet, it should be dried by running it through the screen and spreading it out on top of the density box.



Figure 17. Appearance of soil cast approximately 4.0 percent below Optimum Moisture (left), and easily broken under minimal pressure (right)

The Proctor mold is then assembled and placed on a hardwood block, supported on firm ground or existing pavement, but not on the tailgate of a pickup truck. A layer of soil is placed in the mold in a quantity sufficient to fill one-third of its volume after compaction. The soil is then compacted in the mold by 25 blows of a 5.5-pound rammer, dropping 12 inches as shown in Figure 9. While compacting the soil, the rammer should be moved about the soil surface in the mold to obtain uniform compaction of each layer. It is important that the rod be held vertically and the rammer weight dropped freely since it is a standard compactive effort. Any increase or decrease in the effort may materially affect the accuracy of the test. A second layer of soil is added, filling another one-third of the volume of the mold after compaction. This too is compacted by 25 evenly distributed blows. The third and final layer is added, including enough soil to extend slightly above the top of the mold, after compaction. The third layer is compacted by 25 evenly distributed rammer blows. After the collar has been removed, the compacted soil should extend $\frac{1}{4}$ to $\frac{1}{2}$ inch above the top of the mold as shown in Figure 10 (top). If the soil does not extend above the mold or if it extends more than $\frac{1}{2}$ inch above the mold, the test should be repeated.

The material is struck-off even with the top of the mold using the strike-off bar, as shown in Figure 10 (bottom). If stones are encountered at this level, stones extending above the mold more than halfway are removed, stones extending less than half way are driven in with the blunt edge of the strike-off bar. Any remaining voids should be filled with fine material..

c. WEIGHING THE SAMPLE

Next, the base plate is removed and the mold is weighed to the nearest gram (Figure 12). This weight is recorded in Column D (Wet Soil + Mold) on the density form (Form 0582B). The volume of the mold and its weight when empty are painted on its side. This weight is recorded in Column E (Mold) and this volume in Column C (Volume Mold).

d. COMPLETING THE TEST PROCEDURE

The sample is removed from the mold by loosening the handle on the mold and pushing out the soil. The moisture content of the soil is determined by the "Speedy" moisture tester. Refer to page 56 for instructions on the use of the "Speedy." The Moisture % is entered in Column B of Form 0582B.

Complete the computations through Column H (Compacted Soil Wet) as shown in Figure 11. This is accomplished by subtracting the weight of the mold (Column E) from the weight of the material and mold (Column D). The result is recorded in Column F (Wet Soil). Convert the weight in grams (Column F) to pounds by dividing by 453.59 and record in Column G (Wet Soil, lbs.). The Compacted Soil Wet (Column H) is determined by dividing the Wet Soil (Column G) by the volume of the mold (Column C).

e. COMPLETING THE FULL TEST CURVE

The soil remaining in the mold is again broken up by running it through the screen and mixed with the remainder of the original sample. Water is added to raise the moisture content approximately 2 percent. An experienced inspector can judge moisture content by the feel and appearance of the soil. A novice inspector should weigh the total

sample and compute 2 percent of that weight to determine the amount of the water needed. The water is added and the sample is thoroughly mixed by working the soil through the screen until the water is uniformly distributed throughout.

After the sample has been broken up and mixed, the same procedure (compacting three layers in the mold, obtaining the moisture content, and determining the Compacted Soil Wet) is followed. This procedure is repeated until there is a decrease in the Compacted Soil Wet (Column H). Ordinarily this will require 4 or 5 molds of varying moisture contents to determine moisture-density results for the complete curve.

f. DETERMINING MAXIMUM DENSITY AND OPTIMUM MOISTURE

A graph is then prepared with a horizontal leg (abscissa) showing Moisture % and the vertical leg (ordinate) showing the Compacted Soil Wet values in pounds per cubic foot. The Compacted Soil Wet and moisture content from each test are plotted on the graph. A smooth parabolic curve is then drawn through these points.

The apex or high point of the parabolic curve gives the Maximum Density and Optimum Moisture of the particular soil. The Maximum Density is recorded in Column I and Optimum Moisture % in Column J. It can be seen after plotting a curve why it is necessary to have at least four points to establish a definite peak. Two points are needed on each side of optimum to establish the slopes of the parabolic curve, which are nearly straight lines.

g. PRECAUTIONS IN PERFORMING THE AASHTO T-99 TEST

This test establishes a moisture-density relationship; thus, it is important that the compactive effort is standard and uniform throughout the entire series of molds to ensure accuracy of the results. Experience has shown that the following items are important to keep in mind when performing this test:

- 1) Establish a new Maximum Density any time the material changes (minimum of one per day) or the percent compaction exceeds 100.0.
- 2) Have the sample thoroughly broken up by running it through the screen before pounding.
- 3) Make sure the clamp on the collar and mold is tight.
- 4) Make sure the mold is seated squarely on the base and the wing nuts are secured with equal tension.
- 5) Place the mold on a hardwood block that is supported on firm soil or pavement.
- 6) Hold the rammer vertically so that it will fall freely.
- 7) Drop the 5.5-pound rammer weight freely for each 12 inch blow.
- 8) Use exactly 25 blows on each layer.

- 9) Reposition large stones away from the sides of the mold and away from other stones to prevent voids.
- 10) Place 3 equal layers in the mold.
- 11) Use enough material in the third layer so that, when compacted, the material extends $\frac{1}{4}$ to $\frac{1}{2}$ inch above the top of the mold. If the third layer is not above the top of the mold or more than $\frac{1}{2}$ inch above, repeat the test.
- 12) Break up and screen the sample thoroughly and mix the water evenly into the sample before each succeeding test is started.
- 13) Pound enough molds at varying moisture contents to provide at least 2 points on each side of optimum for the graph.
- 14) Record Maximum Density (Column I) as well as Optimum Moisture % (Column J) on Form 0582B, as obtained from the plotted curve.
- 15) Additional precautions for weighing and moisture sampling for this test and others are provided in the appendix.

3. THE ONE-POINT MICHIGAN CONE TEST

a. DESCRIPTION

An adaptation of the Michigan Cone Test is the One-Point Michigan Cone Test which derives its name from the fact that only one cone needs to be compacted. The One-Point Michigan Cone Test is used to determine Maximum Density of granular soils having a loss-by-washing of 15 percent or less. This includes aggregate base courses and Granular Material Classes I, II and III. Research has shown that the One-Point Michigan Cone and Michigan Cone Test produce a higher Maximum Density in granular soils than the AASHTO T-99 Test.

The equipment for this test is shown in Figure 2. This consists of an inverted funnel-shaped mold (cone) having a solid bottom at the large end, a stopper, a hardwood pounding block, a plastic water bottle and a One-Point Michigan Cone Chart (Figure 18). The equipment shall be calibrated/checked annually.

b. PREPARING, COMPACTING AND WEIGHING THE SAMPLE (SAND OR GRAVEL)

A sample from the In-Place Density test of approximately 3500 grams is used in this test. A 10 inch by 10 inch pan (furnished in all density kits) filled level to the top usually contains enough material. Any stones that freely fit in the opening of the cone remain part of your sample.

For the One-Point Michigan Cone Test, soil moisture content must be between **5.0 percent and optimum moisture**. The In-place test will provide you with a moisture value. If the sample has a moisture content below 5.0 percent add water after the sample has been collected and not to the grade at the test location. Be certain the water is evenly mixed throughout the sample. If the sample has to be dried or have

water added, then determine the moisture content using the “Speedy” moisture tester after performing the One-Point Michigan Cone. Refer to page 56 for instructions on the use of the “Speedy.” Record the resulting Moisture % in Column B of Form 0582B. Place a circled “S” in the box to indicate that the Moisture % was determined by the “Speedy” moisture tester.

Place enough soil in the cone to fill it about one-third of its **height after compaction**. It is then pounded 25 times or more by raising the cone above the hardwood pounding block and striking it sharply, flat on the end grain of the block (Figure 19). A second layer is added, filling the cone about two-thirds of its **height after compaction**, and pounded 25 times or more. The third layer, which fills the cone to the top, is added and pounded another 25 times or more. **After the third layer has been compacted, the cone is again filled to the top and then 10 blows or more are continued, holding a hand or stopper over the opening. Material is added at intervals to keep the mold full. Continue pounding until no further consolidation occurs (Figure 20). A common error in this test is to discontinue the blows before it is certain that no more material can be compacted into the cone.** If free water appears at the top of the cone the material is saturated. The moisture content should be reduced by drying the sample and the test is repeated.

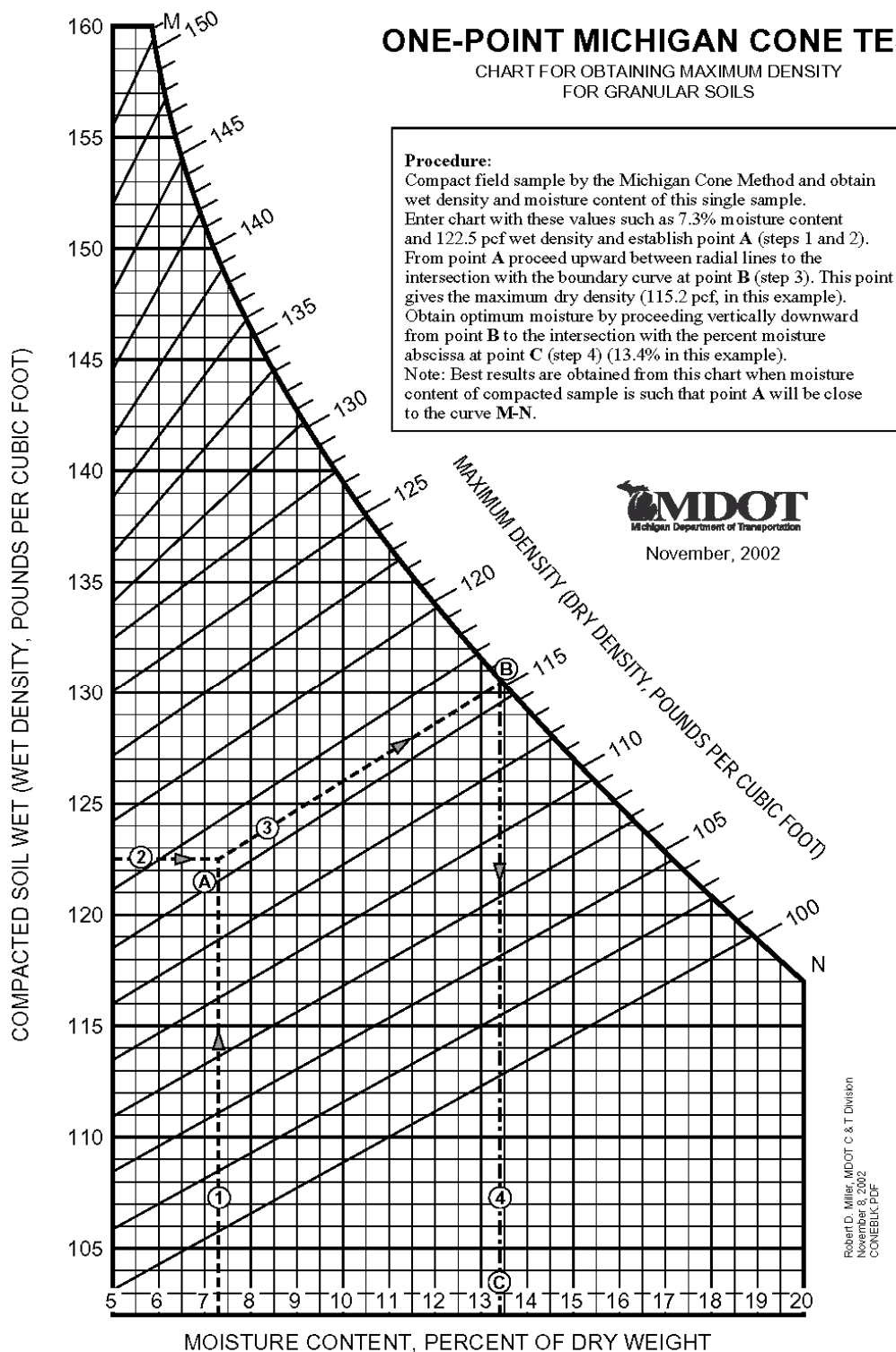


Figure 18. One-Point Michigan Cone Test Chart



Figure 19. Striking cone on block

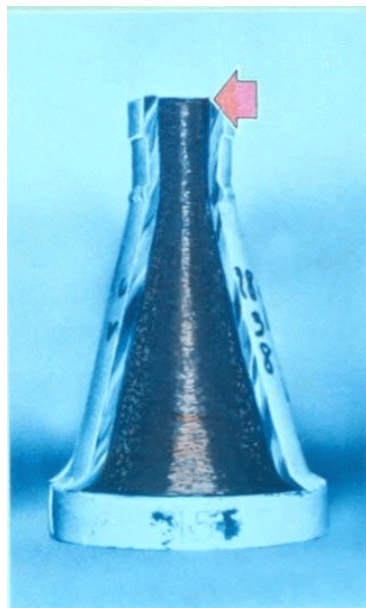


Figure 20. Cross-section of properly compacted cone mold

TEST NUMBER	MOISTURE %	VOLUME MOLD CU. FT.	DETERMINATION OF MAXIMUM DENSITY (SOIL & HMA)							NOTE: To convert (g) to (lbs.): Wt. (g) ÷ 453.59 = Wt. (lbs.)																
			WET SOIL + MOLD g	MOLD g	WET SOIL g	WET SOIL lbs	COMPACTED SOIL WET PCF	MAX DENSITY PCF	OPTIMUM MOISTURE %																	
A	B	C	D	E	F	G	H	I	J	CHART STANDARDS																
1	7.3	0.0458	3,818	1,273	2,545	5.61	122.5	115.2	13.4	DENSITY	MOISTURE															
										2,757	755															
										2,702	725															
										OPERATING STANDARDS																
										DENSITY	MOISTURE															
										2,710	736															
REMARKS																										
Initial weight= 3799																										
<table border="1"> <thead> <tr> <th>20/10 Weights</th> <th>1st</th> <th>2nd</th> <th rowspan="2">DENSITY INSPECTOR'S APPROVAL STAMP</th> <th rowspan="2">AGENCY/COMPANY</th> </tr> </thead> <tbody> <tr> <td></td> <td>3,810</td> <td>3,818</td> <td></td> <td></td> </tr> <tr> <td>3rd</td> <td>4th</td> <td>5th</td> <td></td> <td></td> </tr> </tbody> </table>												20/10 Weights	1st	2nd	DENSITY INSPECTOR'S APPROVAL STAMP	AGENCY/COMPANY		3,810	3,818			3rd	4th	5th		
20/10 Weights	1st	2nd	DENSITY INSPECTOR'S APPROVAL STAMP	AGENCY/COMPANY																						
	3,810	3,818																								
3rd	4th	5th																								

Figure 21. Entries and computations for the One-Point Michigan Cone Test

After the cone is fully compacted, the material is leveled off the top using a straight-edge or the stopper. The cone is then weighed to the nearest gram. The weight is recorded in the "remarks" section of Form 0582B, Moisture and Density Determination.

In order to verify that the maximum consolidation has been obtained, the following procedure must be followed. This procedure is commonly referred to as the **20/10 Rule**, and is intended to determine the correct end point for the One-Point Michigan Cone Test.

A small handful of material is added to the top of the cone and the cone is pounded an additional 20 times. The material is again struck level and the cone is re-weighed to the nearest gram. The weight obtained is then compared to the previously recorded weight. If the increase in weight is 10 grams or less, maximum consolidation has been obtained and the test is complete. Record the final weight, the highest weight obtained, in column D (Wet Soil + Mold) as indicated in Figure 21. If the increase in weight, the highest weight is greater than 10 grams, maximum consolidation has not been obtained, and the process is repeated as needed until the incremental change in weight is less than or equal to 10 grams.

The volume and the weight of the cone are painted on the bottom of the cone. The volume of the mold is recorded in Column C (Volume Mold) and the weight is recorded in Column E (Mold).

Empty the cone by striking the open end (**not the sides of the cone**) on the wood block.

Note: The cone should be checked periodically for accuracy by the Area Density Specialist. The weight and the volume of the cone should never be changed in the field. These values can only be changed when the cone is recalibrated.

c. DETERMINING MAXIMUM DENSITY AND OPTIMUM MOISTURE

A preliminary step in determining the Maximum Density is to complete the computations through Column H (Compacted Soil Wet) as shown in Figure 21. This is accomplished by subtracting the weight of the mold (Column E) from the weight of the material and mold (Column D). The result is recorded in Column F (Wet Soil). Convert the weight in grams (Column F) to pounds by dividing by 453.59 and record in Column G (Wet Soil, lbs.). The Compacted Soil Wet (Column H) is determined by dividing the Wet Soil (Column G) by the volume of the mold (Column C).

Maximum Density is found by applying the Moisture % (Column B) and the Compacted Soil Wet (Column H) values to the One-Point Michigan Cone Test Chart shown in Figure 18.

Assume that the results from a One-Point Michigan Cone Test are as follows: Compacted Soil Wet (Column H) (or “Wet Density”) is 122.5 pounds per cubic foot and the Moisture % (Column B) (or “Moisture Content”) is 7.3 percent. Locate the Moisture Content on the horizontal leg (abscissa) and the Wet Density on the vertical leg (ordinate) and then project the lines on the chart as indicated by the dashed line **1** and **2** to intersection **A** (Figure 22). Next project point **A** upwards and to the right, as indicated by dashed line **3** to an intersection **B** with the outer boundary curve. This point of intersection **B** is the Maximum Dry Density or Maximum Unit Weight, in this case 115.2 pounds per cubic foot (Figure 23). Enter the result in Column I (Maximum Density) of the “Determination of Maximum Density” section shown in Figure 21.

To obtain Optimum Moisture, proceed downward vertically from point **B** as indicated by dashed line **4** to intersect the horizontal leg (abscissa) at point **C**. The percentage shown at point **C** is the Optimum Moisture, in this case 13.4 percent (Figure 24). Enter the result in Column J (Optimum Moisture %) of the “Determination of Maximum Density” section shown in Figure 21.

If point **A** falls to the right of the Maximum Density curve, the soil is too wet. The moisture content should be reduced by drying the sample and the test is repeated.

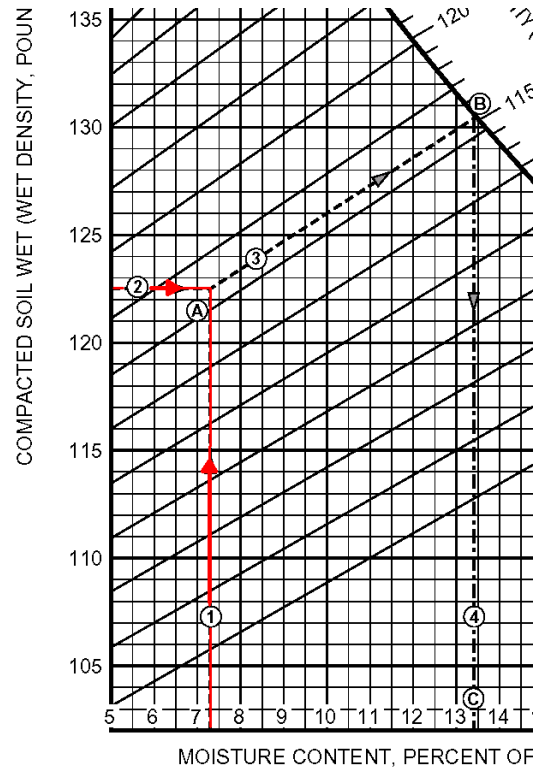


Figure 22. Steps 1 and 2

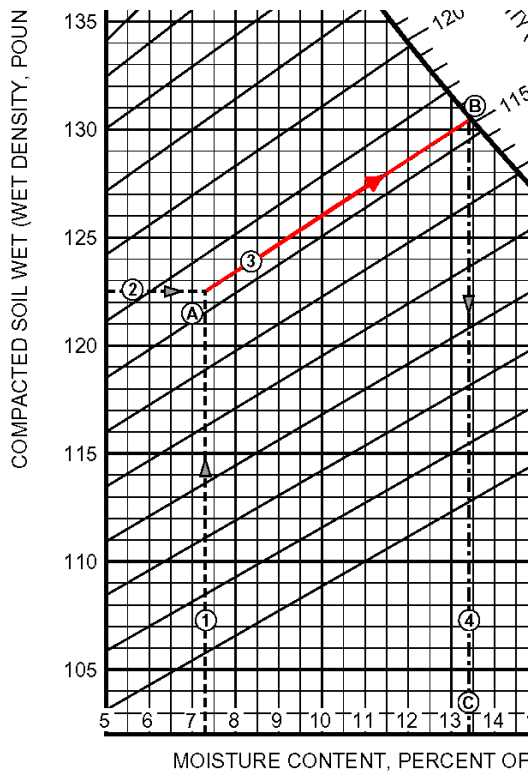


Figure 23. Step 3

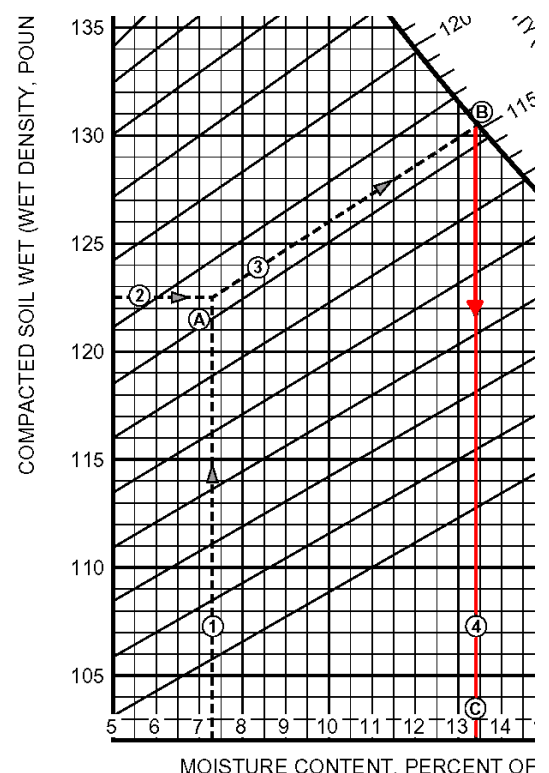


Figure 24. Step 4

d. PRECAUTIONS IN PERFORMING THE ONE-POINT MICHIGAN CONE TEST

Experience has shown that the following items are important to keep in mind when performing the One-Point Michigan Cone Test:

- 1) Establish a new Maximum Density any time the material changes (minimum of one per day) or the percent compaction exceeds 100.0.
- 2) Sample must have a moisture content between 5.0 percent and optimum moisture. If necessary, add water to the collected sample and not to the grade at the test location.
- 3) Use a hardwood pounding block placed on firm ground, not on the pickup tailgate.
- 4) Strike the cone squarely on the end grain of the block.
- 5) **Pound the cone until no more consolidation occurs.**
- 6) Check for maximum consolidation by the **20/10 Rule**.
- 7) Empty the cone by inverting it and lightly striking the open end on the face of the block. **Do not empty by striking the cone on its side, as this can cause dents which may change the volume.**
- 8) Take the moisture sample from material at the center of the cone.
- 9) If the point on the chart obtained by plotting the Compacted Soil Wet (Column H) and Moisture % (Column B) falls to the right of the Maximum Density curve, the sample is too wet. The sample should be dried and the test repeated.
- 10) Determine the Maximum Density and Optimum Moisture % to the nearest tenth.
- 11) Record the Maximum Density (Column I) and Optimum Moisture % (Column J) on Form 0582B.
- 12) Clean out the cone after each test. Soil residue remaining in the cone may cause errors in weight and volume in the next test. Cleaning is easily done by shaking a few stones in it.
- 13) Check the empty cone weight periodically. If any change is observed, contact the Area Density Specialist. The cone should be recalibrated by qualified personnel only.
- 14) Maximum Density cannot be determined using a cone if the sample is saturated.
- 15) Additional precautions for weighing and moisture sampling for this test and others are provided in the appendix.

4. THE MICHIGAN CONE TEST

a. DESCRIPTION

The Michigan Cone Test is a series of cone tests used to determine Maximum Density of granular soils having a loss-by-washing of 15 percent or less, used as a referee or supplemental test to the One-Point Michigan Cone. It is usually performed in a lab setting and used by the inspector at the direction of the Area Density Specialist. The equipment used is the same as that used for the One-Point Michigan Cone Test (Figure 2) except for the One-Point Michigan Cone Test Chart. The equipment shall be calibrated/checked annually.

b. PREPARING, COMPACTING AND WEIGHING THE SAMPLE (SAND OR GRAVEL)

The weight of the representative sample of sand or gravel used in this test is approximately 3500 grams. A 10 inch by 10 inch pan (furnished in all density kits) filled level to the top usually contains enough material.

For all granular materials, the moisture content must be at least **5.0 percent**. This may require the addition of water for most granular soils and aggregates. Mix the water thoroughly with the material.

Enough soil is placed in the cone to fill it about one-third its **height after compaction**. It is then pounded 25 times or more by raising the cone above the hardwood pounding block and striking it sharply, flat on the end grain of the block (Figure 19). A second layer, filling the cone about two-thirds its **height after compaction**, is added and pounded 25 times or more. The third layer, which fills the cone to the top, is added and pounded another 25 times or more. **After the third layer has compacted, the cone is again filled to the top and then 10 blows or more are continued, holding a hand or stopper over the opening. Material is added at intervals to keep the mold full and then 10 blows or more are continued until no further consolidation occurs (Figure 20). A common error in this test is to discontinue the blows before it is certain that no more material can be compacted into the cone.** If free water appears at the top of the cone, the material is saturated. The moisture content of the sample should be reduced and the test repeated.

After the mold is fully compacted, the material is leveled off the top, using a straight-edge or the stopper. The cone is then weighed to the nearest gram. This weight is recorded in Column D (Wet Soil + Mold) as shown in Figure 21. The volume and weight of the cone when empty are painted on the bottom. This volume should be recorded in Column C (Volume Mold) and the weight in Column E (Mold).

The weight of the cone should be checked periodically for any change. The cone should occasionally be checked for volume accuracy by the Area Density Specialist, since the repeated poundings may bulge the bottom of the cone and change its volume. If any change is observed, the cone should be recalibrated for weight and volume by qualified personnel only.

After the cone has been weighed, obtain a moisture sample from the center of the cone sample. Empty the cone by striking the open end (**not the sides of the cone**) on the wood block.

c. DETERMINING MOISTURE CONTENT (SAND OR GRAVEL)

The moisture content is determined using the “Speedy” Moisture Tester. Refer to page 56 for instructions on the use of the “Speedy.” The Moisture % is entered in Column B of Form 0582B.

d. DETERMINING MAXIMUM DENSITY OF GRANULAR SOIL OTHER THAN PROCESSED AGGREGATES

Complete the computations through Column H (Compacted Soil Wet) as shown in Figure 21. This is accomplished by subtracting the weight of the mold (Column E) from the weight of the material and mold (Column D). The result is recorded in Column F (Wet Soil). Convert the weight in grams (Column F) to pounds by dividing by 453.59 and record in Column G (Wet Soil, lbs.). The Compacted Soil Wet (Column H) is determined by dividing the Wet Soil (Column G) by the volume of the mold (Column C).

If the result of Column H (Compacted Soil Wet) is less than 120 pounds per cubic foot and the moisture content is between 5 percent and optimum, the Maximum Density is the result of one cone test. Enter this result in Column I (Maximum Density).

If the result of Column H (Compacted Soil Wet) is more than 120 pounds per cubic foot, a series of two or three cone tests should be repeated at varying moisture contents between 5 percent and a point short of saturation. Suggested moisture contents for the cone series are 7, 9 and 11 percent. The highest test result of this series of cones is the Maximum Density or Maximum Unit Weight and is entered in Column I.

e. DETERMINING MAXIMUM DENSITY OF AGGREGATE BASE COURSE AND SURFACE AGGREGATES

Research has shown that moisture content does have an appreciable effect on Maximum Unit Weight of gravel. This weight is greatest within 5 to 8 percent moisture content. Thus, the Maximum Density of aggregates is determined at a moisture content ranging from 5 to 8 percent, as follows:

- 1) Run a series of cone tests with moisture content of the aggregate at different points within the 5 to 8 percent range. Two or three points within this range generally should be sufficient to determine the highest unit weight. For example, one test could be run at approximately 5 percent moisture, a second at approximately 6 percent moisture and a third at approximately 7 percent moisture.
 - a) If the cone is saturated (free water appears at the top of the cone), reduce the moisture content but not below **5.0 percent**. If the cone test is run on saturated aggregate, the results may be inaccurate.
 - b) If the aggregate in the cone exhibits the “swell” effect (rises slightly above the top of the cone), reduce the moisture content but not below **5.0 percent**.

- 2) The highest test result of the series of cones within the 5 to 8 percent moisture range is the Maximum Unit Weight or Maximum Density.

f. PRECAUTIONS IN PERFORMING THE MICHIGAN CONE TEST

Experience has shown that the following items are important to keep in mind when performing the Michigan Cone Test:

- 1) Establish a new Maximum Density any time the material changes (minimum of one per day) or the percent compaction exceeds 100.0.
- 2) Use a hardwood pounding block placed on firm soil, not on the pickup tailgate.
- 3) Strike the cone squarely on the end grain of the block.
- 4) **Pound the cone until no more consolidation occurs.**
- 5) Empty the cone by inverting it and lightly striking the open end on the face of the block. **Do not empty by striking the cone on its side, as this can cause dents which may result in changes in volume.**
- 6) As nearly as can be estimated, take the moisture sample from material at the center of the cone.
- 7) Clean out the cone after each test because soil residue will cause errors in weight and volume in the next test. This is easily done by shaking a few stones in it. Do not dry the cone over an open flame.
- 8) Check the empty cone weight periodically. If any change is observed, the cone should be recalibrated only by qualified personnel.
- 9) The Area Density Specialist should check the weight and volume of the cone periodically.
- 10) Do not perform cone tests on saturated sands or gravels.
- 11) Additional precautions for weighing and moisture sampling in this test and all others are provided in the appendix to this manual.

5. THE MICHIGAN MODIFIED T-180 TEST

a. DESCRIPTION

The Michigan Modified T-180 Test is a modification of AASHTO T-180 (Method C) Test. This test is used to determine the Maximum Density of recycled mixtures containing pulverized HMA and/or concrete pavement used as aggregate base course or other appropriate items of work. This test also applies to material stabilized with HMA used as aggregate base course. The test is performed at existing moisture content, short of saturation, on material with a maximum top size of 1 inch. The Maximum Density is

determined on a wet weight basis which is calculated using the total weight of the sample, which includes both the weight of the solids and the weight of the water.

The equipment used for the Michigan Modified T-180 Test is shown in Figure 3. It consists of a cylindrical mold (Proctor mold) of 4 inches in diameter, with a detachable collar and base plate; a 10-pound rammer with an 18 inch drop; a sharp-edge strike-off bar; and a hardwood pounding block. The equipment shall be calibrated/checked annually.

b. OBTAINING AND COMPACTING THE SAMPLE

The sample of material to establish the Wet Maximum Density should be obtained from the exact location of the In-Place Test. This is very important because the Wet Maximum Density is established at the **existing moisture content**. Enough material should be obtained to fill the 10 inch by 10 inch pan and thoroughly mixed for even distribution of the existing moisture.

The Proctor mold is assembled and placed on a hardwood block, supported on firm ground or existing paved surface. Enough material is placed in the mold to fill one-fifth of its volume after compaction. The material is then compacted in the mold by 25 blows of the 10-pound rammer weight, dropping 18 inches as shown in Figure 25. While compacting the material, the rammer should be moved about the material surface in the mold to obtain uniform compaction of the layer. It is important that the rod be held straight and the rammer weight dropped freely since it is a standard compactive effort. Any increase or decrease in the effort can significantly affect the accuracy of the test. A second, third, and fourth layer of material is added, each layer being compacted by 25 blows and each layer filling approximately one-fifth of the volume of the mold. The fifth and final layer of material is then added, including enough material to extend $\frac{1}{4}$ to $\frac{1}{2}$ inch above the top of the mold after compaction. The fifth layer of material is also compacted by 25 blows. After the collar has been removed, the compacted material should extend $\frac{1}{4}$ to $\frac{1}{2}$ inch above the top of the mold as shown in Figure 26. If the material does not extend above the mold, or if the material extends more than $\frac{1}{2}$ inch above the mold, the test should be repeated.

The material is struck-off even with the top of the mold using the strike-off bar as shown in Figure 27. Large voids in the surface of the molded sample should be filled using the fines of the sample and pressed down with the strike-off bar and struck-off.



Figure 25. Recycled material being compacted in the mold



Figure 26. Mold with collar removed and recycled material $\frac{1}{4}$ to $\frac{1}{2}$ inch above the top of mold



Figure 27. Mold with the material struck-off even with the top of the mold

c. WEIGHING THE SAMPLE

Next, the base plate is removed and the mold and sample are weighed to the nearest gram (Figure 28). This weight is recorded in Column D (Wet Soil + Mold) on Form 0582B as shown in Figure 29. The volume and weight of the mold when empty are painted on the side. The volume is recorded in Column C (Volume Mold) and the weight in Column E (Mold).



Figure 28. Weighing the mold and recycled material to the nearest gram

d. DETERMINING WET MAXIMUM DENSITY

The Wet Maximum Density can now be determined by completing the computations through Column H (Compacted Soil Wet) as shown in Figure 29. This is accomplished by subtracting the weight of the mold (Column E) from the weight of the material and mold (Column D). The result is recorded in Column F (Wet Soil). Convert the weight in grams (Column F) to pounds by dividing by 453.59 and record in Column G (Wet Soil, lbs.). The Compacted Soil Wet (Column H) is determined by dividing the Wet Soil (Column G) by the volume of the mold (Column C). The Compacted Soil Wet (Column H) is also the Wet Maximum Density and should be recorded in Column I (Maximum Density).

A new Maximum Density should be determined any time the material changes, or the moisture changes by more than ± 1.5 percent. As stated previously, for the Michigan Modified T-180 test, the Maximum Density is determined at the existing moisture content and multiple Maximum Density values may be necessary as the moisture content of the material changes. For example, after taking an In-Place density test and determining a Wet Maximum Density, the In-Place density test did not meet requirements. The contractor, before applying more compactive effort, elects to add water to the area of the failing test. After the failing area is further compacted, the area is retested with another In-Place test. If the same Maximum Density was used for the retest, the test would probably pass, not because of the additional effort so much as from the addition of water.

It is possible to obtain passing retests just by adding water if the previous Maximum Density obtained at a lower moisture content is still used. Whenever water is added to a failing area, a new Wet Maximum Density must be established when the In-Place retest is taken.

Page 1 of 2

DATE 09/30/2023	CONTROL SECTION ID 33010	JOB NUMBER 90270A	ROUTE NUMBER or STREET Farm Lane - MSU Campus	GAUGE NUMBER 207926
DENSITY INSPECTOR Justin Foster	CERTIFICATION NUMBER 50685-0225	DENSITY INSPECTOR PHONE NUMBER 517-636-4970	CONSTRUCTION ENG. (MDOT) M. Smith	ASST. CON. ENG/CONSULTANT ENG. J. Williams

[illegible]

Moisture Range for Max Density #3 = 4.6 - 7.6

Figure 29. Entries and computations for Michigan Modified T-180 Test

e. PRECAUTIONS IN PERFORMING THE MICHIGAN MODIFIED T-180 TEST

Experience has shown the following items are important to keep in mind when performing the Michigan Modified T-180 Test:

- 1) Determine the Wet Maximum Density at the **existing moisture content** (normally several will have to be performed each day).
- 2) Perform the In-Place Tests in the “Asphalt Mode”.
- 3) Use the same material as used for the In-Place Test.
- 4) Make sure the pounding block is placed on a compacted grade surface or existing pavement.
- 5) Hold the rammer perpendicularly so the weight falls freely for each 18 inch blow.
- 6) Use exactly 25 blows on each layer.
- 7) Compact 5 equal layers in the mold.
- 8) Use enough material in the fifth layer so that the compacted material extends $\frac{1}{4}$ to $\frac{1}{2}$ inch above the top of the center section of the mold.
- 9) Establish a new Wet Maximum Density any time the material changes, **moisture changes by more than $\pm 1.5\%$** or the percent compaction exceeds 100.0.
- 10) Enter Wet Maximum Density as a **Marshall** value.

6. THE DENSITY IN-PLACE (NUCLEAR) TEST**a. DESCRIPTION**

The department currently uses the Troxler Model 3400 series and the InstroTek Xplorer Model 3500 portable nuclear gauges for field density control. All gauges used for Quality Assurance testing must be calibrated annually.

All gauges contain radioactive sources and are regulated by the NRC and the U.S. DOT.

The gauge uses a scaler display which records the radiation emitted from a source which passes through the soil and is picked up by detector tubes. The principle involved is that dense materials absorb more radiation than less dense material. The lower the scaler display reading, the higher the density of the material.

The gauge also measures the amount of moisture in the material being tested. This is accomplished by the gauge source emitting “fast” neutrons and only detecting “slow” neutrons. The hydrogen in the moisture slows the “fast” neutrons to a rate of speed the detector tubes can pick up and count. The more moisture, the more hydrogen, resulting

in more “slow” neutrons for the tubes to detect, thereby giving a higher value for moisture content.

When not in use, the source rod must be fully retracted in the SAFE position. When the Troxler gauge is lifted by the handle, the source rod automatically returns to the SAFE position.

b. LOCATION AND FREQUENCY OF TEST

The Density In-Place Test should be taken in those areas of fill (embankment) or backfill that appear to be the least compacted. The test area is selected by watching the movement of the contractor’s compaction equipment. If the tests are run in the visibly poorer areas and they meet specification requirements, it may be assumed that the remainder of the test section also meets specifications. The controlled density specifications require each layer to be compacted to a minimum of 90, 95, 98, or 100 percent of Maximum Density, depending on the item of work. Details on frequency of testing are provided in the appendix of this manual.

The gauge offers the option to test by Direct Transmission or Backscatter. Always use Direct Transmission tests on soil and recycled materials. The Backscatter test is used only on Hot Mix Asphalt mixtures.

c. TROXLER MODEL 3440

In this manual and in the density certification class the Troxler Model 3440 gauge is used.

The Troxler Model 3440, as shown in Figures 30 and 31, is a direct transmission gauge. Mechanically, this gauge is the same as the older Model 3411B. The 3440 gauge also contains a microprocessor which is programmed to perform a wider range of functions and has larger memory capacity for ease of operation. The 3440 gauge is more user friendly than the 3411B which prompts the user during testing and shows more information in the display window.

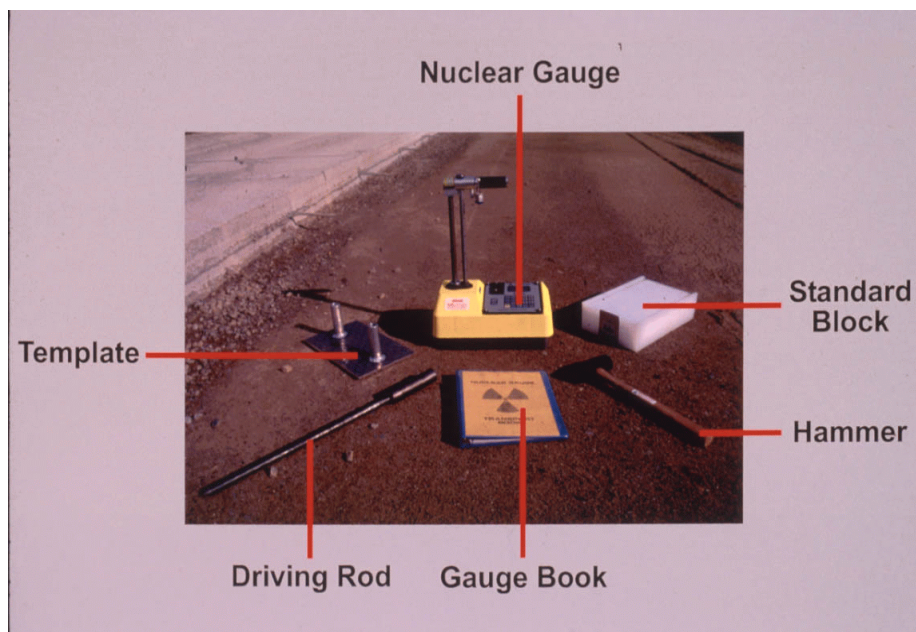


Figure 30. Troxler Model 3440 nuclear gauge



Figure 31. Troxler Model 3440 controls

1) Keys Description

Below is a functional description of the keys found on the Model 3440 control panel:

KEYS	DESCRIPTION
YES EXIT	Answers display prompt. Permits exit from the calculator mode.
NO/CE C/CE	Answers display prompt/Clear last entry. Clears calculator entry.
STATUS 7	(SHIFT function) Display status of gauge functions. Number key.
MODE 8	(SHIFT function) Asphalt or Soils selection. Number key.
SPECIAL 9	(SHIFT function) Provides access to special functions. Number key.
STORE MS	To store data in gauge memory. Memory store function for the calculator mode.
OFFSET MR	Select measurement offsets. Memory recall function for the calculator mode.
PROJECT 4	(SHIFT function) To enter, view or erase a project Number key.
PRINT 5	(SHIFT function) Download data Number key.
ERASE 6	(SHIFT function) Erase data Number key.
PROCTOR/MARSHALL +	Proctor or Marshall value selection. Addition sign for calculator functions.
TIME -	Selects time interval for testing and measurement. Subtraction sign for calculator functions.
COUNTS 1	(SHIFT function) Displays last moisture and density counts. Number key.
DEPTH 2	(SHIFT function) Automatic or manual depth operation. Number key.
CALC. 3	(SHIFT function) To access the calculator mode. Number key.
SHIFT x	Activates all SHIFT function modes. Multiplication sign for calculator functions.
STANDARD /	Provides access to standard count mode. Division sign for calculator functions.
RECALL 0	(SHIFT function) To recall data for viewing Number key.
.	Decimal point key
START/ENTER =	See manual text and index. Equals sign for calculator functions

2) 3440 Keypad Layout

The Troxler Model 3440 control panel consists of 22 keys (Figure 31): the 20 key control section and the ON/OFF keys. Keystrokes result in an immediate “beep”

from the gauge. If the beep is not heard, the operation has not been completed. Gauge and control panel operation are described throughout the manual.

SHIFT and SHIFT FUNCTION keys are color coded yellow for ease of identification. SHIFT must be pressed before pressing a function key. Functions are directly addressable from any other function except the calculator mode. Pressing SHIFT causes the top line display to change to <SHIFT FUNCTION>.

Note: If a function key is not pressed within 4 seconds, the gauge reacts as if no key was pressed. If there is no action after pressing a key, the gauge will return to READY after 2 minutes.

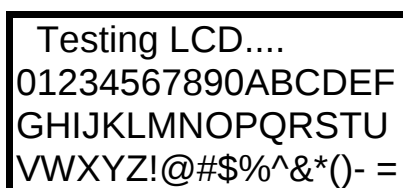
YES, NO and START/ENTER keys apply to all gauge modes. Pressing START/ENTER from most modes will abort the mode and begin a test.

3) Turning the Gauge On

The gauge uses rechargeable Ni-Cad batteries as a power source. When first turned on, the display screen will fill with test characters before proceeding to the ram test and the self-test phase.

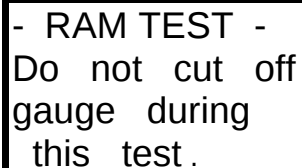
To turn the gauge on, press **ON**.

The display is the LCD test:



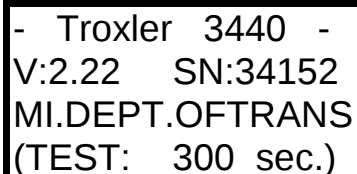
Testing LCD....
01234567890ABCDEF
GHIJKLMNOPQRSTU
VWXYZ!@#\$%^&*()- =

After 2 seconds, the display will change to:



- RAM TEST -
Do not cut off
gauge during
this test.

The gauge will perform the ram test. After the ram test, the display will be:



- Troxler 3440 -
V:2.22 SN:34152
MI.DEPT.OFTRANS
(TEST: 300 sec.)

The gauge will undergo a 300 second self-test. After the self-test, the display will be:

READY	9:10 AM
Depth:	SAFE POS.
Time:	1.00 MIN
Batt volts:	7.5

Alternating between the date and time, the READY display will be shown each time the gauge is ready to proceed to another function or there is no activity for more than 2 minutes.

Under certain conditions, the gauge will shut itself off after 5 hours of no activity.

4) Recharging the Batteries

The READY display shows the amount of voltage left in the battery packs and will be shown as "Batt volts: 7.5". When the voltage in the battery packs drops below 7.0 volts the gauge will indicate **<Batteries low!>**. Never recharge the batteries unless the gauge indicates a **<Batteries low!>** condition. It takes a 16 hour charge to completely recharge the battery packs. A 30 minute recharge will allow the gauge to be used for another 8 to 10 hours. Don't leave the charger hooked up to the gauge over a weekend.

5) Taking the Standard Counts

Note: The front of the gauge is closest to you when the 3440 is placed with the source rod to the left and the control panel to the right. The handle contains the trigger mechanism, used to position the source rod on the notched index rod. The source rod should always be in the SAFE position when the gauge is not in use.

A new operating standard must be obtained each day before doing any testing. The gauge should be turned ON before leaving for the project site. This allows the gauge to go through the self-test routines. The gauge should be ON for approximately 20 to 30 minutes before attempting to run the standard counts. From the Gauge Book, obtain the standard counts established when the gauge was calibrated and record in the lower right hand corner of Form 0582B, (Figure 29) under Chart Standards. Place the standard block on a flat surface of sound earth a minimum of **6 feet** away from any large object (vehicles, structures, etc.) or wet area (puddles, streams, etc.). Prior to placing the gauge on the standard block, be certain the top of the block and the bottom of the gauge are clean. The gauge must be positioned between the raised edges of the block and with the scaler end of the gauge up tight against the metal butt plate on the block. Remove the lock from the trigger and make certain the handle is indexed in the SAFE position.

To begin taking a standard count, press **STANDARD** for the display:

- Standard Count -
DS = _____
MS = _____
Take new count?

Press **YES** for the display:

Is gauge on Std.
Block & Source
rod in SAFE pos?

Make sure the gauge is placed on the reference block correctly. Place the source rod in the SAFE position and press **YES** to begin taking the 4 minute standard count:

Taking
Standard Count
240 seconds
remaining

After count completion, the display is:

MS= _____ . _ %P
DS= _____ . _ %P
Do you want to
use the new STD?

The standard count (operating standard) should not deviate from the chart standards obtained from the Gauge Book by more than 1 percent for density or 2 percent for moisture. If the standard counts are within acceptable limits, press **YES** to accept. Record the standard counts in the lower right corner of Form 0582B, (Figure 29) under Operating Standards. If either value is out of range, press **NO** and take another standard count. Before repeating the standard count, make sure the gauge base and reference block are clean and the gauge is positioned correctly on the reference block. If either standard is still out of tolerance, call the Area Density Specialist or Lansing Density Technology staff immediately to make arrangements to have the gauge serviced or replaced. The gauge should be serviced or replaced within 24 hours.

To determine if the gauge can continue to be used until serviced or replaced, do the following:

Repeat the standard count procedure 5 times, saving each result when prompted. On completion of the fifth standard count, check the display to determine status. If

the standards for the fifth count are within tolerance, ± 1 percent for density and ± 2 percent for moisture, a **P** will show next to the percentages in the display. If passing results are indicated, you may continue to use the gauge for 24 hours. If either standard fails, an **F** will show on the display and the gauge should be taken out of service immediately.

6) Viewing the Last Four Standard Counts

To “view” the last 4 standard counts, press **STANDARD** for the display:

-Standard Count-

DS = ____

MS = ____

Take new count?

Press **NO** for the display:

- Standard Count -

Want to view

last four

Standard Counts?

Press **YES** for the display:

Density Std Cts

1: ____ 2: ____

3: ____ 4: ____

(YES for Moist)

To view the “Moisture Standard Counts” press **YES**. The display will be:

Moist. Std Cts

1: ____ 2: ____

3: ____ 4: ____

(Press any key)

The “View Standard Count” function may be exited by pressing any key.

7) Count Time Selection

The 3440 gauge provides 3 different count times to be used for taking readings. **When running In-Place Moisture/Density Tests always use the 1 minute time cycle.** Never use the 15 second time cycle.

Press **TIME** for the display:

Time: _____ min
1 - 15 sec
2 - 1 min
3 - 4 min

Press **2** to select 1 minute count:

- Count Time -
1 min

After a short delay, the display will return to READY.

8) Mode Selection

The Mode function provides for the selection of SOIL or ASPHALT mode. Under ASPHALT mode, the sub-mode selection of “% Marshall” is always used.

To select the Mode Functions, press **SHIFT** and **MODE** for:

MODE: _____
Select: 1- SOIL
2- ASPHALT
(CE to exit)

a) Soils Mode Selection

From the Mode Selection display, press **1** to select SOIL mode. The display will be:

SOIL MODE

After a short delay, the display will return to READY.

b) Asphalt Mode Selection

From the Mode Selection display, press **2** to select ASPHALT mode. The display will be:

ASPHALT: _____
Select: 1- %MA
 2- 100 -%MA
(CE to exit)

Asphalt Mode - % Marshall

$$\% \text{ Marshall} = (\text{WD}/\text{Marshall}) \times 100$$

Select “% Marshall” by pressing **1** from the Asphalt Mode Selection display. The display will be:

ASPHALT: %MA
Do you want to
ENABLE %VOIDS
also?

Always press **NO** when it asks if you want to enable “% Voids.”

9) Density/Moisture Measurement**a) Soils Mode**

Enable the SOIL mode prior to taking a measurement. Check units of measurement, count time and Maximum Density.

After the test site is selected, the surface of the soil to be tested must be prepared. Surface condition is very important and can affect gauge performance and the accuracy of test results. Using the template as a scraper, smooth the test surface. Place the template on the surface and move it back and forth in all directions to smooth the test site. Remove the template and fill small depressions or voids present with sand or fine material available near the test site.

Place the template on the surface again and press down firmly to level. Using your foot to hold the template firmly, advance the drill rod to the desired test depth. When running tests on soils, always use one of the “Direct Transmission” test positions (2, 4, 6 or 8 inches). Select the depth of test based on thickness of the layer being tested. The test depth must be at least 2 inches from the bottom of the layer but no more than 3 inches. Still holding the template firmly with your foot, twist the drill rod and remove it by pulling straight up. Do not loosen the drill rod by tapping from side to side with the hammer. Once

removed, use the drill rod to scribe along 3 sides of the template. After removing the template, place the gauge on the test site and insert the source rod into the driven hole to the desired test depth (2, 4, 6 or 8 inches). Select the depth of test based on thickness of the layer being tested. The test depth must be at least 2 inches from the bottom of the layer but no more than 3 inches. Facing the scaler end of the gauge, pull the gauge toward you to seat the source rod against the side of the driven hole.

To start the measurement, press **START/ENTER** for the display:

Depth: ____ inches
PR: _____ PCF
Time: ____ sec.

After the gauge completes its count time, the display will be:

%PR= _____ %
DD= _____ PCF
WD= _____ PCF
M= _____ %M= _____

Record DD, WD, M and %M in the correct columns on Form 0582B.

Note: Do not record %PR until the correct Maximum Density has been enabled.

To obtain the density and moisture test counts press **SHIFT** and **COUNTS** for the display:

Dens ct.= _____
Moist ct.= _____
SHIFT/RECALL to see Readings.

Record the counts in columns 4 and 5 on Form 0582B.

b) Asphalt Mode

Enable the ASPHALT mode prior to taking a test on HMA materials. Check units of measurement, count time and Maximum Density.

Select the test site and make sure the site is flat before setting the gauge down. Place the source rod in the BACKSCATTER position.

Start a measurement by pressing **START/ENTER**. The display will be:

Depth: __	inches
MA: _____	PCF
Time: ____	sec.

After the gauge completes its count time, the display will be:

%MA= _____	%
WD= _____	PCF
M= _____	%M= _____

Record WD, M and %M in the correct columns on Form 0582B.

Note: Do not record %MA until the correct Maximum Density has been enabled.

To obtain the density and moisture test counts press **SHIFT** and **COUNTS**. Record the counts in columns 4 and 5 on Form 0582B.

10) Proctor (Cone)/Marshall/Voidless Function

The 3440 gauge provides for up to four different Proctor (Cone) values and four different Marshall values to be stored for later use.

To select or change a Proctor (Cone) or Marshall Density value press the **PROCTOR /MARSHALL** key for the display:

MA= _____	PCF
PR= _____	
VD= _____	
Want to change?	

If a value is to be enabled or a new value added or changed, press **YES**. The display is:

Select:
1 - MA
2 - PR
3 - Voidless

Marshall and Proctor (Cone) functions are identical as far as operation is concerned. Therefore, only Proctor (Cone) will be illustrated. To change a Proctor (Cone) value, press **2** for:

Select source of
Proctor value:
1- Stored value
2- New value

a) Recall a Stored Proctor (Cone) / Marshall Value

To enable a previously stored value, press **1**. The display is:

Select desired
Proctor:
1: _____ 2: _____
3: _____ 4: _____

Select the desired Proctor (Cone) value by pressing **1, 2, 3** or **4** for the display:

Proctor:
_____ PCF
ENABLED!

b) Enter a New Proctor (Cone)/Marshall Value

From this display press **2**. The display will be:

Select source of
Proctor value:
1- Stored value
2- New value

Proctor:
_____ PCF
Press ENTER
when completed

Enter the new value and press **ENTER** for the display:

PR=_____ PCF
Do you want to
save this value
for later use?

Press **YES** to save the new Proctor (Cone) value in a memory cell, for later use.

The display will be:

Select Proctor	
Memory cell:	
1: _____	2: _____
3: _____	4: _____

Select the desired Proctor (Cone) memory cell by pressing **1**, **2**, **3** or **4**. The display will be:

Proctor:
_____ PCF
ENABLED!
stored in cell _____

11) Recall Function

RECALL displays the last density and moisture readings.

Press **SHIFT** and **RECALL**. For SOIL mode, the display will be:

%PR=_____%
DD=_____ PCF
WD=_____ PCF
M=_____ %M=_____

Press **SHIFT** and **RECALL**. For ASPHALT Mode, the display will be:

%MA=_____%
WD=_____ PCF
M=_____ %M=_____

Record the percent of compaction, %PR or %MA, in column 11 on Form 0582B.

12) Depth Function

The DEPTH function allows the user to select one of two depth modes; manual or automatic. In the MANUAL mode, the gauge prompts the user to **manually** input the source rod depth using the keypad. In the AUTOMATIC mode, the gauge **automatically** reads the depth strip on the index rod and then determines the source depth. To set the DEPTH mode, press **SHIFT** and **DEPTH**.

a) Manual Mode

If the DEPTH mode is set to AUTOMATIC, the gauge display is:

Depth Ind: Auto
1- Select MANUAL
2- Calibrate
(CE to exit)

To set the DEPTH mode to MANUAL, press **1** for:

Depth Indicator:
MANUAL

b) Automatic Mode

If the DEPTH mode is set to MANUAL, the gauge allows the user to change the mode. After changing the mode to AUTOMATIC, the gauge permits the user to calibrate the depth strip.

NOTE: In the AUTOMATIC depth mode, the user should calibrate the depth after extreme changes in temperature. The gauge automatically calibrates the depth when the user takes a standard count. The gauge also allows the user to calibrate the gauge as follows.

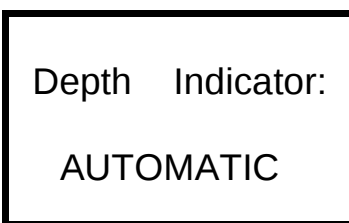
To calibrate the depth, press **SHIFT** and **DEPTH**:

Depth Ind: Auto
1- Select MANUAL
2- Calibrate
(CE to exit)

Press **2**. The screen displays:

-DEPTH Calib -
Set rod at:
SAFE POSITION
and press ENTER

Position the source rod in the SAFE position and press **ENTER**. The gauge calibrates the depth. It then indicates that the depth indicator is in the AUTOMATIC mode as shown below, and returns to the READY display.



d. INSTROTEK 3500 Xplorer 2

1) Keys Description

Below is a functional description of the keys found on the Xplorer 2 control panel:

Key	Description
YES / ON	Use this key to power on the gauge. When the gauge is on, use this key to answer YES to questions asked during the operation of the gauge.
NO / OFF	Use this key to power off the gauge. When the gauge is on, use this key to answer NO to questions asked during the operation of the gauge.
STD	Use this key to take a Daily Reference Standard Count. Place your gauge on top of the Polyethylene reference block on top of a solid surface (soil, asphalt, or concrete) press this key and follow gauge prompts. A new standard count is accumulated and is used in the gauge calculations until another reference standard count is collected. Powering off the gauge will not erase the most recent standard count.
TIME	Use this key to adjust the measurement count time. The time of measurement options are: 15-seconds, 30-seconds, 1-minute, and 4-minutes. Press the TIME key, use UP and DOWN to change, and follow the screen prompts to select the time. Press the YES key to return to the <READY> screen. NOTE: All acceptance testing on MDOT and/or Federal aid jobs must be done in 1-minute time cycle.
PROJECT	Use this key to access the Project storage. Auto-store may be enabled or disabled. Projects may be created, selected, reviewed, deleted, or sent to a printer or USB drive. Use UP and DOWN to advance through the numbers assigned to the button.
PRINT	Use this key to send data to the USB and/or send projects via the serial port. Use UP and DOWN to access either of these functions.
STORE	Press this key to manually store a measurement into a project after a measurement is completed.
MAX PR	Use this key to enter your field established maximum density values such as Marshall or Proctor in the Gauge. Use the number keys to input the desired values. Press the ENTER key after completing the entry to accept the input value. The gauge uses this value to calculate %PR for cohesive and granular or %MA for HMA and recycled. %MA is defined as the calculated percentage of the gauge density value relative to the value of maximum density entered by the operator. It can also be used for determination of %Compaction. The most recently added entry is stored in the gauge.
MENU	Option 1 – <u>Recall:</u> Allows the user to retrieve the most recent gauge test results. Option 2 – <u>Offset:</u> This mode provides three different offset functions, Moisture, Density, and Trench correction. Consult an authorized person before enabling these functions. Option 3 – <u>Auto Scroll:</u> Helps user during recording of data in the field. The test screens automatically scroll every 5 seconds. Option 4 – <u>LCD Backlight:</u> Allows easy viewing of data and keypad during night work. Option 8 – <u>Auto-Depth:</u> Enable or Disable the Auto Depth Feature. Select the Depth Strip

2) Powering the Gauge On

Use the YES/ON key to power the gauge on. When the gauge is powered on the Xplorer 2 will go through the following Self-Test screens:

Xplorer 2
Version: #.##

Self-Test will take approximately 15 seconds and checks for proper operation of the keypad, density, and moisture detectors. Place gauge on the standard block during self-test.

Keypad Test in
Progress

Tube Test in
Progress

The Gauge will go to the Ready display after a successful Self-Test. If a failure is detected during Self-Test, one or all of the following messages will display on the screen: Keypad Test Failed, He-3 Tube Failure, GM tube failure.

Important: It is suggested to always power the gauge on and allow the self-test to complete before leaving for a job site. Place the gauge on the reference standard block and check the results of the self-test and ensure there are no failures. Charge the batteries if needed by the provided AC or DC charger (Refer to the section on Charging Batteries).

Note: To preserve battery life for extended gauge operations, the gauge will go into shutdown mode if no key is pressed in one hour. Simply press the **ON** key when you are ready to start again. The gauge will not run the Self-Test if shut down was due to an automatic one hour 'inactive gauge shut down' feature.

3) Recharging the Batteries

The Xplorer 2 contains two sets of three D size NiCd battery packs, a total of six batteries. Also, the front panel has a 9V alkaline battery on the back to provide backup when the NiCd batteries are empty. The NiCd batteries are charged at the factory prior to calibration. Life of rechargeable batteries depends on the number of charge/discharge cycles. For best results, only charge the batteries, when the battery low warning is displayed. There will be a "Recharge Battery" message displayed when the battery is getting low. The gauge will display "ALK" when the NiCd batteries have been drained and the gauge has switched to the alkaline backup.

The provided DC charger can be used for emergency charging in the field. Plug this charger into your vehicle charger outlet and charge the gauge for 30 minutes. This should provide enough battery power to your gauge to complete your testing for the day.

4) Taking the Standard Counts

It is important that a minimum of one daily standard count be taken and ensure that the results are within the range of the expected standard counts provided with the calibration paperwork.

The standard count is used to correct for decay in the radioactive source, especially for the Cs-137 density source. To obtain the most representative standard count in the field, allow the gauge to stabilize to the field environment for a minimum of 15 minutes. Remember the following steps, when taking standard counts:

- Find a level location close to the test site and setup your polyethylene reference standard block.
- Place the gauge on top of the standard block on a level surface; the keypad end of the gauge should be pushed against the metal butt plate.
- Ensure the reference standard block is placed on a dense material, such as soil, asphalt, or concrete. Do not take standard counts on truck tailgates, tables, or non-solid floors. Make sure the bottom of the gauge is clean and resting against the top of the standard block. The gauge should not be resting on the raised edges of the standard block.
- When you place the source rod in the “SAFE” position notch, gently tap it down without pulling the trigger to make sure the handle plunger is properly seated inside the notch. Ensure the handle is reasonably parallel with the gauge.

Press the **STD** button on the front panel. The Standard Count will display with your previous standard count.

DS= #####
MS= ###
Take New Std Count?
Press YES or NO

Press the **YES/ON** button to take a new count or press **OFF/NO** to cancel and go to the gauge ready display.

Place Gauge on Poly
Std. Block in SAFE
Position
Press Start

Press the **START/ENTER** button. In Auto Depth mode, if the source rod is not in the Safe position, the gauge will display a message “Depth not at Safe Position”. The time will begin to count down from 240 seconds (4 minutes).

Standard Count
Time: 240 sec.

After 240 seconds the result of your standard count will be displayed

DS= ####
MS= ###
Use New STD CNT?
Press YES or NO

DS is the density standard count and MS is the moisture standard count. The standard count (operating standard) should not deviate from the chart standards obtained from the Gauge Book by more than 1 percent for density or 2 percent for moisture. If the standard counts are within acceptable limits, record the standard counts in the lower right corner of Form 0582B under Operating Standards. Press **YES/ON** to accept, the gauge ready screen will appear, and you are ready to begin testing. If either value is out of range, press **NO/OFF** and take another standard count. Before repeating the standard count, make sure the gauge base and reference block are clean and the gauge is positioned correctly on the reference block. If either standard is still out of tolerance, call the Area Density Specialist or Lansing Density Technology staff immediately to make arrangements to have the gauge serviced or replaced. The gauge should be serviced or replaced within 24 hours.

To determine if the gauge can continue to be used until serviced or replaced, do the following:

Repeat the standard count procedure 5 times, saving each result when prompted. On completion of the fifth standard count, check the display to determine status. If the standards for the fifth count are within tolerance, ± 1 percent for density and ± 2 percent for moisture, a **P** will show next to the percentages in the display. If passing results are indicated, you may continue to use the gauge for 24 hours. If either standard fails, an **F** will show on the display and the gauge should be taken out of service immediately.

Note: If there are no standard counts in the gauge, a message will display indicating “Invalid Std”. Take a new standard count prior to testing.

5) Viewing Last Thirty Standard Counts

The Xplorer 2 will store the last 30 standard counts in its memory. They can be recalled and reviewed from the MENU functions.

6) Setting Proctor (Soil) / Marshall (HMA & Recycled) Density Values

The gauge is capable of calculating and displaying percent compaction based on user defined field maximum density values. Pressing the MAX/PR button allows the field established value to be entered. Select PR (Proctor) for cohesive and granular materials or Max. Dens. (Marshall) for HMA and Recycled materials. Percent Compaction (%Max and %PR) will be calculated and displayed automatically after each measurement.

Press the **MAX/PR** button.

1. Proctor
 2. Max. Dens
 3. Soil SG

Select #, ESC Exit

Press 1 for setting soil max density value **PR** (Proctor), and
Press 2 for setting HMA or recycled max density value **MAX** (Max. Dens.).
Press 3 for setting soil specific gravity (**SG**). Soil SG is only displayed if this feature was enabled.

Proctor

PR: ###.# PCF
Change value?
Press YES or NO
ESC to Exit

Press the **YES/ON** button

Enter Value For
Proctor: ###.# PCF
ENTER to Accept
ESC to Exit

Once the PR value is entered, the gauge ready screen will display.

Note: To enter a HMA or Recycled max density value, follow the same steps as entering a soil max density. However, you would select option 2 Max. Dens rather than option 1 Proctor after pressing the MAX/PR button.

7) Taking Measurements

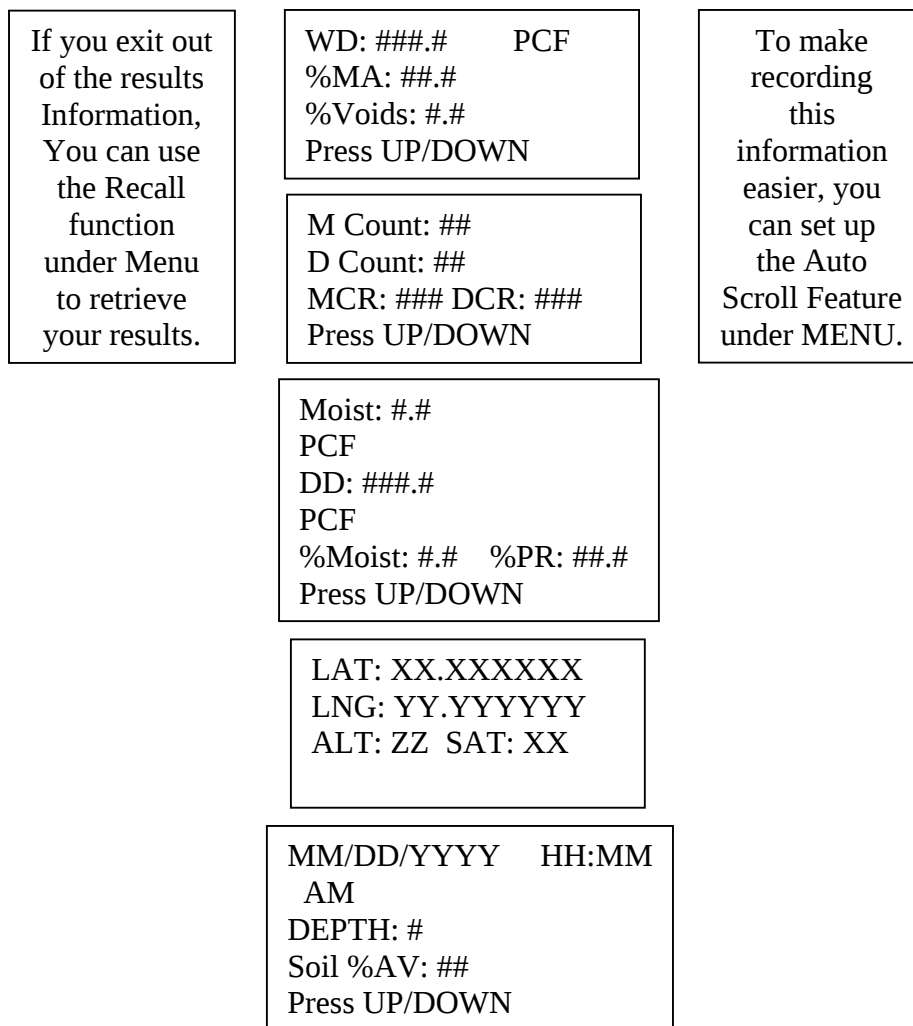
Lower the source rod to the desired depth by pulling the handle trigger back and pushing down on the handle. In positions of measurement, always 'lock' into the position by allowing the trigger to engage the notch and then gently pushing the handle down to 'seat' on the notch.

Caution: Never drive the source rod into the soil by hammering the gauge handle down.

To start measurement, press START/ENTER. The gauge will then begin taking counts.

Depth: #
Time: 1 min

After the gauge has completed its count time, it will display:



8) Measurement Depth

The Xplorer 2 gauge is designed and is equipped with an automatic non-contact magnetic depth indicator. The depth is automatically read as you lower the source into measure position and the appropriate constants are selected for calculation of density.

The gauge can be placed into manual depth mode by disabling the Automatic depth mode from the MENU functions.

9) Where to Record Displayed Data on Form 0582B

M Count = Moisture Count

D Count = Density Count

MCR = Moisture Count Ratio (M Count/MS)

DCR = Density Count Ratio (D Count/DS)

WD = Wet Density

%MAX = Percent of Compaction (HMA & Recycled Materials)

%Void = Percent air voids (100-%MAX)

Moist = Moisture in pounds per cubic feet
DD = Dry Density
%Moist = Moisture percent
%PR = Percent of Compaction (Cohesive & Granular Soils)
LAT = GPS latitude reading (displayed if enabled)
LNG = GPS longitude reading (displayed if enabled)
ALT = GPS altitude in meters
SAT = Number of satellites visible to the GPS module
DEPTH = Position source rod was at during test
Soil %AV = Percent of soil air voids (displayed if enabled)

e. PRECAUTIONS IN PERFORMING THE DENSITY IN-PLACE (NUCLEAR) TEST

- 1) Keep the gauge clean.
- 2) Do not use the gauge during any precipitation. Moisture can damage the gauge resulting in loss of use and costly repairs.
- 3) Contact the Area Density Specialist when the gauge needs servicing.
- 4) Transport the gauge according to US DOT regulations.
- 5) Do not scratch or gouge the surface of the Standard Block.
- 6) **Protect the gauge at all times and handle carefully.**
- 7) Fill holes or voids in the test surface with sand or fine material from the area near the test site.
- 8) Do not recharge batteries unless the battery indicator signals a low battery.
- 9) Be aware of safety standards when the gauge is stored or when charging the batteries.
- 10) If the gauge is involved in an accident, refer to the nuclear gauge transport book.
- 11) **Do not run comparison tests.**
- 12) Return the gauge to its Type A Box in the pickup truck; on the front passenger floorboard or in the bed of the pickup truck or in the NUX Safety Containment Box when not in use.

f. CARE OF NUCLEAR GAUGE AND EQUIPMENT

After the test is completed, the gauge should be returned to the transport case in the cab of the pickup truck. Always secure the gauge in the Type A box prior to transporting the device. Do not transport the gauge on the tailgate or in the bed of the pickup truck as this is in violation of the department's license issued by the Nuclear Regulatory Commission. If the gauge malfunctions, the Area Density Specialist should be notified immediately.

Due to the radioactive materials located within a nuclear density gauge, there are regulations governing the storage, transportation and use of the gauge. The Nuclear Regulatory Commission, United States Department of Transportation and the Michigan Department of Transportation have established safety requirements that must be complied with. These safety requirements include, but are not limited to, the usage, storage, security, transportation of nuclear density gauges, and occupational doses and doses to members of the public. These regulations are located within 10 CFR (Energy) and 49 CFR (Transportation). The safety features built into the Troxler density gauge provide shielding of the radioactive material, which allows an operator to use the gauge while minimizing the exposure to radiation.

1) The following steps must be taken when the gauge is damaged **within** a construction project:

- a) Immediately stop all construction-vehicle movement (in the immediate proximity).
- b) Detain witnesses until they are interviewed.
- c) Establish a fifteen (15) foot perimeter (minimum).
- d) Isolate the gauge from all people.
- e) Contact the Area Density Specialist.
- f) Contact the Statewide Density Specialist
- g) Contact MDOT's Radiation Safety Officer.
- h) Complete an incident report form.
- i) All of the above steps are to be conducted in the order indicated.

2) The following steps must be taken when the gauge is damaged **outside** the limits of a construction project:

- a) Detain witnesses until they are interviewed.
- b) Establish a fifteen (15) foot perimeter (minimum).
- c) Isolate the gauge from all people.
- d) Contact the nearest Michigan State Police Post.
- e) Contact the Area Density Specialist.
- f) Contact the Statewide Density Specialist.
- g) Contact MDOT's Radiation Safety Officer.
- h) Complete an incident report form.

- i) All of the above steps are to be conducted in the order indicated.

3) The following steps must be taken when a gauge is lost or stolen:

- a) Contact the Area Density Specialist.
- b) Contact the Statewide Density Specialist.
- c) Contact MDOT's Radiation Safety Officer.
- d) Contact MDOT's Emergency Management Coordinator.
- e) Complete an incident report form.
- f) All of the above steps are to be conducted in the order indicated.

Refer to the gauge book for the incident report form, telephone numbers and radio numbers.

7. CALCIUM CARBIDE GAS PRESSURE METER ("SPEEDY" MOISTURE TESTER)

a. DESCRIPTION

The Michigan Department of Transportation uses a calcium carbide gas pressure meter for determining moisture content. This test is used when the moisture content of the test sample has been manipulated. The current model in use is the "Speedy" Moisture Tester, which was developed in England and in the soils laboratory of the Federal Highway Administration. Test apparatus must meet the requirements of AASHTO T 217 and be calibrated/ checked annually. Only use pressure meters sized for specimens having a mass of at least 20 grams.

The pressure meter (Figure 32) replaces the two-burner gas stove for the purpose of determining the moisture content of soils. With the pressure meter, the moisture can be determined in five minutes or less which permits obtaining density results much faster than with the stove drying method.

The principle on which the pressure meter is based is a chemical reaction which begins when the soil in the cap and calcium carbide in the body are mixed together. The moisture in the soil combines with the calcium carbide to produce acetylene gas. The gas pressure is registered on the gauge as moisture content, percent of wet weight. When testing very wet soils, an initially high reading and heat are caused by the reaction generated by the higher moisture content. Be sure that the heat has dissipated, and the needle has stopped moving before the final reading.

b. CARE OF THE PRESSURE METER

The density kit contains a place designated to store and work with the equipment. It is important that the pressure meter be carried in this compartment (Figure 5). Within the pressure meter box is a place for each piece of equipment to be stored to prevent

damage to the gauge, the tester, the balance beam and also to prevent the loss of small parts such as the half sample weight (Figure 32).

The care of the pressure meter is important and is the responsibility of the density inspector. The cap in which the soil is placed should be cleaned after each test. The body of the pressure meter should be cleaned before and after each test.

If at any time something is wrong with the equipment, contact the Area Density Specialist.

The cap should be cleaned after each test (Figure 33). A special cloth is provided with each kit for this purpose. This cloth should only be used to clean the cap, the scale pan and the steel balls. The cloth should not be used for any other purpose. Do not blow into the cap as it may contain calcium carbide powder which may cause injury to your eyes.

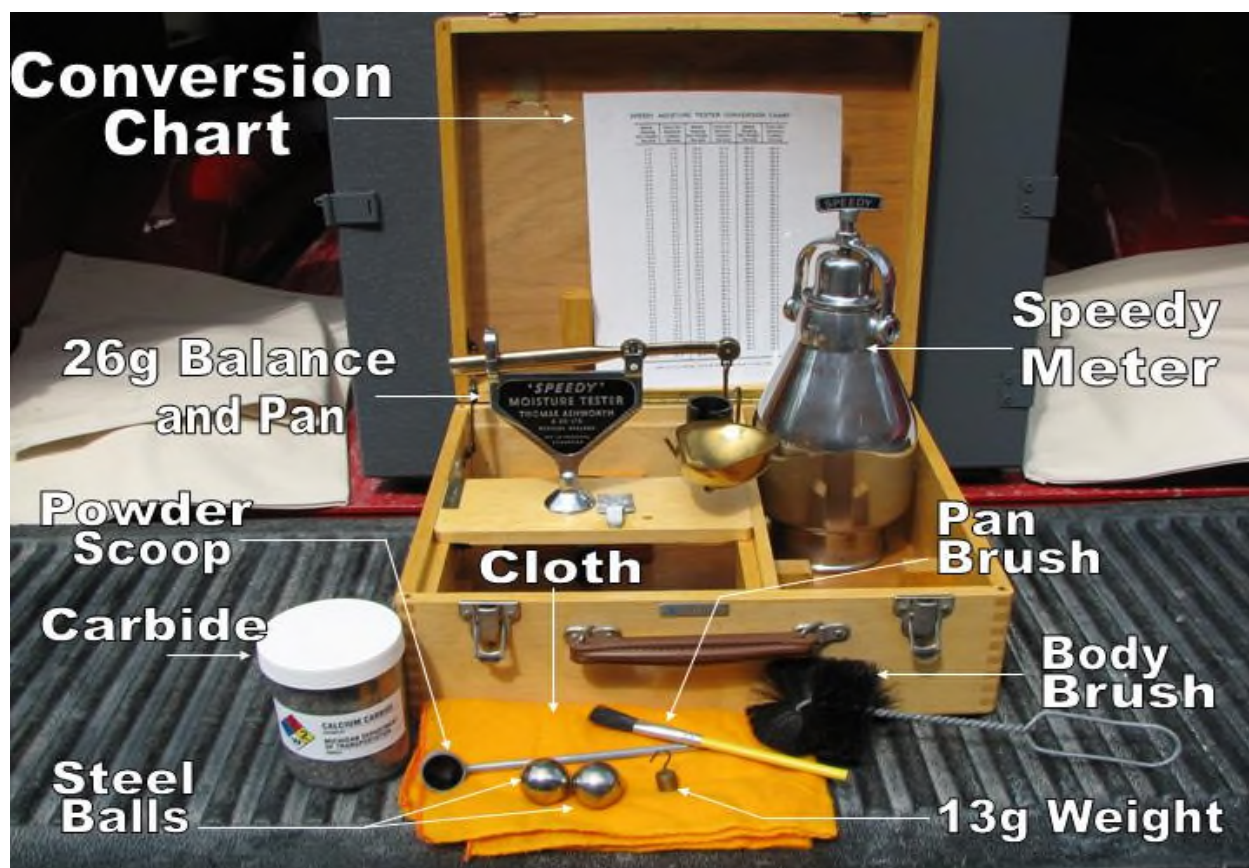


Figure 32. Calcium carbide gas pressure meter ("Speedy")



Figure 33. Proper technique for cleaning the cap of the meter

When cleaning the meter body, use only the brush that comes with the kit (Figure 34). The brush provided is made of a non-conducting material that will not cause static electricity. If anything should happen to the brush, see your Area Density Specialist for a replacement. **DO NOT** use a nylon brush in the meter body which could generate a static charge capable of igniting any residual acetylene gas.



Figure 34. Proper technique for cleaning the body of the meter

This is a precision instrument. While it is considered rugged for its intended use, it will not withstand abuse due to careless handling. The accuracy of test and the useful life of the pressure meter will depend on the skill and technique of the inspector and the general care taken to keep the equipment in good condition.

c. USE OF THE PRESSURE METER

The gauge reading is applied to the conversion chart supplied with each “Speedy” moisture tester (Figure 35).

Note: The gauge reading is based on the wet weight of the sample. The chart converts this to dry weight.

In cold weather, run a sample through the meter to warm up the body. Disregard this reading.

The test procedure is different when testing cohesive soils than when testing granular soils.

SPEEDY MOISTURE TESTER CONVERSION CHART

Speedy Reading Wet Weight Percent	Oven-Dry Moisture Content, Percent	Speedy Reading Wet Weight Percent	Oven-Dry Moisture Content, Percent	Speedy Reading Wet Weight Percent	Oven-Dry Moisture Content, Percent
1.0	1.0	10.8	11.9	20.6	25.0
1.2	1.3	11.0	12.1	20.8	25.4
1.4	1.5	11.2	12.3	21.0	25.6
1.6	1.7	11.4	12.5	21.2	26.0
1.8	1.9	11.6	12.8	21.4	26.3
2.0	2.1	11.8	13.0	21.6	26.5
2.2	2.3	12.0	13.3	21.8	26.8
2.4	2.5	12.2	13.5	22.0	27.2
2.6	2.7	12.4	13.8	22.2	27.5
2.8	2.9	12.6	14.0	22.4	27.8
3.0	3.1	12.8	14.3	22.6	28.1
3.2	3.3	13.0	14.6	22.8	28.4
3.4	3.5	13.2	14.8	23.0	28.7
3.6	3.7	13.4	15.0	23.2	29.1
3.8	3.9	13.6	15.3	23.4	29.4
4.0	4.1	13.8	15.6	23.6	29.8
4.2	4.3	14.0	16.0	23.8	30.0
4.4	4.6	14.2	16.2	24.0	30.3
4.6	4.8	14.4	16.4	24.2	30.6
4.8	5.1	14.6	16.6	24.4	30.9
5.0	5.2	14.8	16.8	24.6	31.2
5.2	5.4	15.0	17.2	24.8	31.6
5.4	5.6	15.2	17.4	25.0	31.9
5.6	5.8	15.4	17.7	25.2	32.2
5.8	6.0	15.6	17.9	25.4	32.5
6.0	6.3	15.8	18.1	25.6	32.8
6.2	6.5	16.0	18.5	25.8	33.1
6.4	6.7	16.2	18.7	26.0	33.6
6.6	6.9	16.4	19.0	26.2	33.8
6.8	7.2	16.6	19.3	26.4	34.0
7.0	7.4	16.8	19.6	26.6	34.3
7.2	7.6	17.0	19.9	26.8	34.7
7.4	7.8	17.2	20.2	27.0	35.0
7.6	8.1	17.4	20.4	27.2	35.3
7.8	8.3	17.6	20.7	27.4	35.6
8.0	8.6	17.8	20.9	27.6	35.9
8.2	8.8	18.0	21.3	27.8	36.2
8.4	9.0	18.2	21.5	28.0	36.6
8.6	9.2	18.4	21.9	28.2	36.9
8.8	9.4	18.6	22.1	28.4	37.2
9.0	9.7	18.8	22.4	28.6	37.6
9.2	9.9	19.0	22.6	28.8	37.9
9.4	10.2	19.2	22.8	29.0	38.2
9.6	10.4	19.4	23.2	29.2	38.5
9.8	10.6	19.6	23.5	29.4	38.9
10.0	11.0	19.8	23.8	29.6	39.3
10.2	11.2	20.0	24.1	29.8	39.6
10.4	11.4	20.2	24.4	30.0	39.9
10.6	11.6	20.4	24.7		

Robert D. Miller, MDOT C&T Division
January 21, 2004
File: SPEEDY.PS

Figure 35. Calcium carbide gas pressure meter (“Speedy”) conversion chart

d. TEST PROCEDURE FOR SAND AND GRAVEL (LOSS-BY-WASHING OF 15 PERCENT OR LESS)

Place 3 scoops of calcium carbide in the body of the “Speedy” (Figure 36).



Figure 36. Place calcium carbide in body of the “Speedy”

Clean the cap in preparation for the sample (Figure 33).

Weigh the sample, obtained from the center of the middle layer of the mold, as quickly and as accurately as possible (Figure 37). The sample will be either 20 or 26 grams, depending on the size of the “Speedy.” Only material passing the $\frac{1}{4}$ inch screen will be used.



Figure 37. Weigh moisture sample

Place the sample in the cap (Figure 38).



Figure 38. Place sample in the cap of meter

Hold the “Speedy” horizontally to prevent the soil and calcium carbide from mixing before the seal is made. Place the cap in position with the body, bring the stirrup around and tighten the top screw (Figure 39).



Figure 39. Fit cap and lock with stirrup and top screw

Hold the “Speedy” upright. Tap the side with your hand to get all the soil from the cap into the body (Figure 40).



Figure 40. Hold the “Speedy” upright; tap the side of the body

Hold the “Speedy” horizontally and rotate to mix the soil with the calcium carbide (Figure 41).



Figure 41. Rotate “Speedy” horizontally

When the needle stops moving, read the result to the nearest tenth. The “Speedy” should be held horizontally when reading the dial (Figure 42).



Figure 42. Read dial with “Speedy” held horizontally

Refer the dial reading to the wet-dry conversion chart, which determines the moisture content based on dry weight. Interpolate to the nearest tenth of a percent (Figure 35). Record the moisture percent (dry weight basis) in Column B, with a circled “S” at the bottom of Form 0582B.

While holding the “Speedy” downwind and away from your body, release the pressure slowly and empty contents (Figure 43).



**Figure 43. Hold “Speedy” downwind and away from body.
Slowly release pressure and empty the “Speedy.”**

Clean the cap and pressure meter body in preparation for the next test.

When using the pressure meter to determine the moisture content of gravels (processed aggregates), the gravel sample must be screened. Using the screen from the density kit, rub the gravel sample through the screen until all of the fines and small stones are through and just the large stones are left. Obtain the moisture sample from the material that has passed through the $\frac{1}{4}$ inch screen.

e. TEST PROCEDURE FOR COHESIVE SOIL (HALF SAMPLE (13 GRAM or 10 GRAM), PROPORTIONAL METHOD and LOSS-BY-WASHING GREATER THAN 15 PERCENT)

Place 3 scoops of calcium carbide in the body of the “Speedy” (Figure 36).

Hold the body of the “Speedy” horizontally. Roll in the two 1-inch steel balls into the body of the “Speedy” (Figure 44). DO NOT drop the steel balls directly into the body of the “Speedy” when it is sitting upright to avoid damaging the orifice of the pressure gauge.



Figure 44. Place steel balls in body of “Speedy” with 3 scoops of calcium carbide

Clean cap with cloth provided in kit (Figure 45).



Figure 45. Cleaning the cap of the meter

Using the $\frac{1}{4}$ inch screen from the density kit, rub the soil sample through the screen (Figure 46).



Figure 46. Using the $\frac{1}{4}$ inch screen from the density kit, always screen cohesive soil before obtaining the moisture sample

Attach the weight to the hook on the right end of the balance arm above the pan. Add material to the pan until the scale comes to balance (Figure 47).



Figure 47. Weigh moisture sample

Place the moisture sample, obtained from the center of the middle layer of the mold, in the cap of the “Speedy” (Figure 38).

While holding the “Speedy” horizontally, place the cap in position and bring the stirrup around and tighten the top screw (Figure 39).

Hold the “Speedy” upright. Tap the side with your hand to get all the soil from the cap into the body (Figure 40).

Hold the “Speedy” horizontally and rotate to put the steel balls in orbit. This mixes the soil and calcium carbide and also breaks down the sample. The mixing time required for heavy clay soils is approximately three to four minutes (Figure 41).

When the needle on the dial stops, read the results to the nearest tenth. The “Speedy” should be held horizontally when reading the dial (Figure 42).

Multiply the dial reading by 2. Refer this result to the wet-dry conversion chart which determines the moisture content based on dry weight to the nearest tenth (Figure 35).

While holding the “Speedy” downwind and away from your body, release the pressure slowly and empty contents (Figure 43).

Inspect the cap. If the cap contains material that was not processed, the test should be repeated.

Clean the cap and pressure meter body in preparation for the next test.

Examine the discarded moisture sample for lumps. If the sample contains clay balls that were not completely broken down, the test should be repeated and the mixing time increased.

f. PRECAUTIONS IN PERFORMING MOISTURE TESTS WITH THE CALCIUM CARBIDE GAS PRESSURE METER (“SPEEDY”)

- 1) Be sure to clean the cap with the cloth provided and the pressure meter body with the brush provided before each test.
- 2) Always hold the “Speedy” horizontally when placing the cap to prevent the soil sample and calcium carbide from mixing before the cap is tightly sealed.
- 3) Be sure the needle on the meter has completely stopped moving before taking the final reading.
- 4) Always empty the “Speedy” by holding downwind and away from your body. The dust is an eye and respiratory irritant and can cause skin burns.
- 5) Do not tap the “Speedy” body with the cap when emptying the contents.
- 6) Use only the brush furnished in the kit to clean the pressure meter body.
- 7) Always screen a cohesive or gravel sample before running the moisture test.
- 8) Do not use the “Speedy” to determine penalty for excessive moisture.

8. REPORTS AND RECORDS

a. GENERAL

The complete and final record of all density tests is made daily on the electronic fillable Form 0582B (Moisture and Density Determination, Nuclear Method).

The section at the top of Form 0582B should be filled in completely. If tests are run on more than one project by the same inspector, a separate form should be used for each project.

The inspector should begin numbering tests each day with No. 1. The test number for each In-Place Density Test is recorded in column 1 under Determination of In-Place Density on the form. All failing tests must be rechecked. The location of the recheck must not exceed **3 feet** horizontally at the same elevation as the original failing test. The recheck test number will be the same as the original test number except it is recorded in column 2. For all rechecks, the date of the original failing test is recorded in column 1.

A test can fail by either moisture or density or both requirements. If a test fails to meet the density requirement, the percent of compaction (column 11) should be circled. If a test fails moisture requirements, the Moisture % (column 9) should be circled.

If the inspector encounters an in-place density test over 100.0% compaction, the test does not fail. However, the inspector must establish a new maximum density with the material obtained from beneath the gauge on that test. This is to ensure that the results at that location are verified and documented or if there has been a change in material that is not visually apparent.

The location of each In-Place Density Test should be recorded by stationing, distance right or left of centerline and depth below plan grade. Identify the item of work (Column 16) using the abbreviations on the back of the form.

Entries on Form 0582B, Determination of In-Place Density, (Columns 6-11) are recorded to the nearest tenth (0.1).

Entries for Determination of Maximum Density are recorded as follows:

Columns D-F	nearest gram
Columns B, H-J	nearest tenth (0.1)
Column C	nearest ten-thousandth (0.0001)
Column G	nearest one-hundredth (0.01)

When conducting a recheck, if the Maximum Density is imported from a previous report, recopy the complete Maximum Density line from the original report. Record the date of the original test in the margin to the left of the test number.

See examples of Form 0582B in Figures 48 to 51.

The distribution for Form 0582B is as follows: ORIGINAL to the project file and COPIES to the Area Density Specialist and Lansing Density Technology Unit.

Form 0582B must be submitted by the tester to the office daily.

Distribution of Form 0582B to the Area Density Specialist and the Lansing Density Technology Unit must be made weekly at a minimum.

Electronic submittal of test reports shall be sent to the Lansing Density Technology Unit at the following address:

MDOT-NuclearDensityTestReports@Michigan.gov

Michigan Department
of Transportation
0582B (10/2023)

MOISTURE AND DENSITY DETERMINATION NUCLEAR METHOD

Page 1 of 2

DISTRIBUTION: Construction Engineer, Area Density Specialist, Density Technology Unit (Lansing).

DATE 09/30/2023		CONTROL SECTION ID 33010		JOB NUMBER 90270A		ROUTE NUMBER or STREET Farm Lane - MSU Campus		GAUGE NUMBER 207926	
DENSITY INSPECTOR Justin Foster		CERTIFICATION NUMBER 50685-0225		DENSITY INSPECTOR PHONE NUMBER 517-636-4970		CONSTRUCTION ENG. (MDOT) M. Smith		ASST. CON. ENG/CONSULTANT ENG. J. Williams	

TEST			DETERMINATION OF IN-PLACE DENSITY								LOCATION OF TEST				
ORIGINAL	RECHECK	TEST DEPTH inch	COUNTS (MC)	COUNTS (DC)	DRY DENSITY PCF	WET DENSITY PCF	MOISTURE PCF	MOISTURE %	MAX DENSITY PCF	PERCENT OF COMPACTION	STATION	DISTANCE FROM CL ft		DEPTH BELOW PLAN GRADE ft	ITEM OF WORK
												LEFT	RIGHT		
1		8	212	2103	114.2	133.2	19.0	16.6	119.0	96.0	62+50		6	2.0	E
09/30	1	8	147	2,316	114.9	127.6	12.7	11.1	119.0	96.6	62+50		6	2.0	E
2		8	128	2,600	109.5	120.3	10.8	9.9	112.6	97.2	60+00	5		1.0	S
3		8	135	2,585	108.9	120.5	11.6	10.7	112.6	96.7	58+00		3	1.0	S
4		8	54	2,510	115.5	119.7	4.2	3.6	116.0	99.6	100+00	2		6.0	B
5		8	80	2,489	112.9	119.1	6.2	5.5	116.0	97.3	100+00		3	6.0	B
6		4	93	3,371	129.6	137.1	7.5	5.8	133.7	96.9	52+00		5	0.5	AB
7		4	98	3,254	132.8	141.1	8.3	6.3	133.7	99.3	50+00	3		0.5	AB
09/30	6	4	95	3,314	131.2	139.1	7.9	6.0	133.7	98.1	52+00		5	0.5	AB

TEST NUMBER	MOISTURE %	VOLUME MOLD CU. FT.	DETERMINATION OF MAXIMUM DENSITY (SOIL & HMA)							NOTE: To convert (g) to (lbs.): Wt. (g) ÷ 453.59 = Wt. (lbs.)
			WET SOIL + MOLD g	MOLD g	WET SOIL g	WET SOIL lbs	COMPACTED SOIL WET PCF	MAX DENSITY PCF	OPTIMUM MOISTURE %	
A	B	C	D	E	F	G	H	I	J	CHART STANDARDS
1	12.0	0.0366	4,506	2,320	2,186	4.82	131.7	119.0	13.1	DENSITY 2,757 2,702 MOISTURE 755 725
2	9.9	0.0460	4,033	1,462	2,571	5.67	123.2	112.6	14.2	
4	7.9	0.0460	4,053	1,462	2,591	5.71	124.2	116.0	13.1	DENSITY 2,710 MOISTURE 736
6	5.8	0.0460	4,359	1,462	2,897	6.39	138.8	133.7	8.4	

REMARKS
 MD test #2 Initial weight = 3970 MD test #4 Initial weight = 3999 20/10s: 4020, 4049, 4053
 MD test #6 Initial weight = 4130 20/10s: 4175, 4250, 4330, 4355, 4359
 Test #1 fails moisture percent, over optimum

20/10 Weights	1st 3,990	2nd 4,013	DENSITY INSPECTOR'S APPROVAL STAMP	AGENCY/COMPANY MDOT - Lansing TSC
3rd 4,025	4th 4,033	5th		

Figure 48. Form 0582B: Density Determination of Soils

Michigan Department
of Transportation
0582B (10/2023)

MOISTURE AND DENSITY DETERMINATION

Page 1 of 2

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[illegible]

Figure 49. Form 0582B: Density Determination of HMA Aggregate Base (BAB) Mixtures

Michigan Department
of Transportation
0582B (10/2023)

MOISTURE AND DENSITY DETERMINATION

Page 1 of 2

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[illegible]

Figure 50. Form 0582B: Density Determination of HMA Mixtures

DENSITY REQUIREMENTS

	MINIMUM % OF COMPACTION	ITEM OF WORK	SPEC. BOOK SECTION
Roadway Earthwork			
Subgrade for HMA Base, Aggregate Base and Concrete Widening	95.0	SG	205.03 E or F
Earth Excavation where material does NOT meet Sand Subbase Requirements	95.0	CN	205.03 G
Earth Excavation where material does meet Sand Subbase Requirements	95.0	CS	205.03 G
Embankments			
Sound Earth	95.0	SE	205.03 H.4
Regular	95.0	E	205.03 H.4.a
Structure Embankment - Original Ground	95.0	OG	205.03 I.1
Abutments with Piling – within the limits for Structure Embankment as shown on the plans	95.0	AP	205.03 I.2.a
Abutments without Piling – within the limits for Structure Embankment as shown on the plans	100.0	AN	205.03 I.2.b
Backfill			
Foundation Backfill for Bridges, Pump Stations, Retaining Walls and Culverts (other than pipe.)	100.0	FB	206.03 B.2.a
Backfill for Bridges, Culverts, Sewers, Water Main, Manholes, Catch Basins, Edge Drains and Subgrade Undercuts	95.0	B	Various
Pavement Structure			
Subbase	95.0	S	301.03
Subbase for Slope Paving	90.0	SP	813.03 A
Aggregate Base - used under Concrete Pavement	95.0	SS	302.03 A
Aggregate Base - used under HMA Pavement	98.0	AB	302.03 A
Aggregate Base – sleeper slab footprint and approach area	98.0	SLA	302.03 A
OGDC – used under Concrete and HMA Pavement	95.0	OGDC	303.03
OGDC – sleeper slab footprint and approach area	95.0	SLO	303.03
OGDC – used under Concrete and HMA Pavement (recycled material)	95.0	OGR	303.03
OGDC – sleeper slab footprint and approach area (recycled material)	95.0	SLOR	303.03
Crushed Concrete Aggregate Base – used under Concrete Pavement (recycled material)	95.0	CAC	302.03 A
Crushed Concrete Aggregate Base – used under HMA Pavement (recycled material)	98.0	CAB	302.03 A
HMA Aggregate Base - pulverized HMA used under HMA Pavement (recycled material)	98.0	BAB	305.03 C
Trenching – under concrete pavement	95.0	TC	307.03 A
Trenching – under HMA pavement	98.0	TB	307.03 A
Shoulders – Class I	98.0	SAA	307.03 C
Shoulders – Class II and III	95.0	SA	307.03 C
HMA Stabilization	98.0	BS	
HMA Paving – Base Course	92.0*	BB	Special Provision
HMA Paving – Leveling Course	92.0*	BL	
HMA Paving – Top Course	92.0*	BT	
See JMF (form 1911) for Gmm value for target density value. TMD=Gmm x 62.4			
*Minimum % compaction of JMF TMD			

Figure 51. Page 2 of Form 0582B Showing Density Requirements

b. PRECAUTIONS FOR RECORDS AND REPORTS

Experience has shown the following items are important to keep in mind when recording test results:

- 1) Report all tests, failing or passing, on Form 0582B.
- 2) Check all calculations.
- 3) Circle percent of compaction and/or moisture percent for all failing tests.
- 4) All failing tests require a passing retest.
- 5) Use original test number and date to identify retests.
- 6) Use the “Remarks” space at the bottom of Form 0582B to document failing tests and when corrections and retests were not completed on the same date.
- 7) Submit original test reports to the office daily. Retyped or recopied versions are not acceptable.
- 8) Distribution of Form 0582B to the Area Density Specialist and the Lansing Density Technology Unit must be made weekly at a minimum.
- 9) Electronic submittal of test reports shall be sent to the Lansing Density Technology Unit at the following address:

MDOT-NuclearDensityTestReports@Michigan.gov

II. TECHNICIAN QUALIFICATION PROGRAM FOR FIELD DENSITY TESTING

A. TECHNICIAN QUALIFICATIONS

Technicians performing field density testing must be certified and evaluated as necessary by Independent Assurance Test (IAT) in accordance with the following criteria:

1. Certification.

Technicians performing Quality Assurance testing on departmental projects must become certified and maintain certification through a program conducted or approved by the MDOT Construction Field Operations Section, Density Technology Unit.

2. Independent Assurance Tests (IAT).

- a. NHS routes.

Technicians who perform density testing on federal aid projects on the National Highway System (NHS) must be evaluated by an IAT. IAT procedures outlined in the MDOT Quality Assurance Procedures Manual will be used for this evaluation.

- b. Non-NHS routes.

Evaluation by IAT is not required; however, MDOT reserves the right to evaluate technician proficiency using IAT procedures outlined in the MDOT Quality Assurance Procedures Manual.

B. MAINTAINING RECORDS

Construction Field Services (CFS) Construction Field Operations Section maintains a data base which includes the following information for Field Density Testing Technicians:

1. Radiation safety training data
2. Density certification training dates
3. Certification number
4. Expiration date
5. Technician name and address*

* The technician is responsible for informing the department of address change.

The database is updated periodically as training sessions are conducted.

C. DISQUALIFICATION OF TECHNICIANS

1. Falsifying Data.

Technicians found falsifying data will be disqualified from acceptance testing on MDOT and federal aid projects. The term of disqualification may be permanent and will be determined by the Engineer of CFS.

2. Failure to obtain Recertification

Technicians who allow their certification to lapse are not qualified to perform density testing on MDOT or federal aid projects. Reinstatement will be considered only after successful completion of a training program conducted or approved by the MDOT Construction Field Operations Section, Density Technology Unit. The specific coursework necessary for reinstatement will be determined by the Engineer of CFS.

3. Failure to meet the requirements of the IAT program.

a. NHS routes.

Technicians who fail to meet the requirements of the IAT program as outlined in the MDOT Quality Assurance Procedures Manual will be disqualified from acceptance testing on NHS routes.

b. Non-NHS routes.

MDOT reserves the right to evaluate and disqualify technicians from density testing using IAT procedures outlined in the MDOT Quality Assurance Procedures Manual. If evaluation is deemed necessary, technicians failing to meet these requirements may be disqualified from density testing.

4. Other actions deemed detrimental to the MDOT Quality Assurance Program.

III. APPENDIX

A. DEFINITIONS

AASHTO - American Association of State Highway and Transportation Officials.

AGGREGATE - in highway density work this refers to gravel used as base course or shoulder material.

AGGREGATE BASE COURSE FOR HMA SURFACES - the layer or layers of select material of designed thickness placed on a subbase or subgrade to support a HMA surface.

AGGREGATE BASE FOR CONCRETE SURFACES - the layer or layers of select material of designed thickness placed on a subbase or subgrade to support a concrete surface.

AMERICIUM 241: BERYLLIUM - the fixed neutron source in the Troxler nuclear moisture-density gauge used to determine the in-place moisture content of the material being tested.

BACKFILL - material which replaces previously excavated material from trenches or sewers, culverts, etc.; also, fill placed in contact with retaining walls, bridge abutments, etc.

BACKSCATTER TEST - a test ran with the radiation source and detectors in the same horizontal plane.

HMA AGGREGATE BASE - pulverized pavement mixtures consisting of existing Hot Mix Asphalt (HMA surfaces, pulverized and mixed with some portion of the underlying aggregate base. The resulting mixture of pulverized HMA and aggregate base material is then compacted and used as a base course for new or recycled pavement surfaces.

CERTIFY - to award a certificate to (a person) attesting to the completion of a course of study or the passing of a qualifying examination.

CESIUM 137 - the gamma source in the Troxler nuclear moisture-density gauge used to determine the in-place density of the material being tested.

COHESIVE SOILS - fine textured soils bound together (or obtaining strength) by an internal attraction or bond between individual grains, generally clay or clayey soils with loss-by-washing greater than 15 percent.

COMPACTION - densification of a soil or HMA mixture by means of mechanical manipulation.

CONCRETE AGGREGATE BASE - pulverized pavement mixtures consisting of existing concrete surfaces, pulverized and mixed with some portion of the underlying aggregate base. The resulting mixture of pulverized concrete and aggregate base material is then compacted and used as a base course for new or recycled pavement surfaces.

CONSOLIDATION - rearrangement of soil particles to form a more dense material, resulting from either natural or mechanical action.

COUNTS/MINUTE - the amount of radiation picked up by a detector tubes and registered on digital modules or digital indicators for a one-minute period.

DEGRADATION - breakdown of soil particles beyond the natural size of individual grains, by mechanical action or natural processes.

DENSITY - weight per unit volume. See also **DRY DENSITY**, **WET DENSITY** and **MAXIMUM DENSITY**.

DENSITY CONTROL - control of soil or HMA density during construction to ensure that specified values are obtained, as determined by standard tests.

DIRECT TRANSMISSION TEST (Probe Test) - a method which places the source, by means of a probe, into the material to a predetermined depth.

DRY DENSITY - weight per cubic foot of dry soil.

EMBANKMENT - engineered fill, supporting a fill.

FINES - percent of soil particles finer than a No. 200 standard sieve, representing the silt and clay content.

GRANULAR MATERIAL - Michigan specification term, defined as follows:

Material Class	Sieve Analysis (MTM 109) Total Percent Passing (a)									Loss by Washing percent (a) (b)
	6"	3"	2"	1"	1/2"	3/8"	No.4	No.30	No.100	
I			100		45-85		20-85	5-30		0-5
II (c)		100		60-100			50-100		0-30	0-7
IIA (c)		100		60-100			50-100		0-35	0-10
IIAA		100		60-100			50-100		0-20	0-5
III	100	95-100					50-100			0-15
IIIA						100	50-100		0-30	0-15

- Test results based on dry weights
- Use test method MTM 108 for Loss by Washing
- Except for use in granular blankets, Class IIA granular material may be substituted for Class II granular material for projects located in the following counties: Arenac, Bay, Genesee, Gladwin, Huron, Lapeer, Macomb, Midland, Monroe, Oakland, Saginaw, Sanilac, Shiawassee, St. Clair, Tuscola and Wayne Counties.

GRANULAR SOILS - coarse-grained soils with loss-by-washing of 15 percent or less. Granular materials have no cohesion, and derive strength from internal stability.

GRAVEL - rounded or angular particles of rock which will pass a 3 inch sieve and be retained on a No. 10 sieve (AASHTO).

Coarse: passing the 3-inch sieve and retained on the 1-inch sieve.

Medium: passing the 1-inch sieve and retained on the $\frac{3}{8}$ inch sieve.

Fine: passing the $\frac{3}{8}$ inch sieve and retained on the No. 10 sieve.

HOT MIX ASPHALT (HMA) AGGREGATE BASE - a pulverized HMA material mixed with the underlying aggregate base, compacted and used as a base for HMA surface.

HOT MIX ASPHALT (HMA) MIXTURES - HMA mixtures used as bases, binders, leveling and top courses.

LOSS-BY-WASHING - an estimate of the percentage of soil fines (% passing the no. 200 sieve). That fraction of the soil sample that is subject to suspension in water and can be decanted from the balance of the sample hydraulically.

MAXIMUM DENSITY - dry density (unit weight) of a material obtained by a specified amount of compaction at the existing moisture content.

MOISTURE CONTENT - the quantity of moisture in a soil expressed as a percentage of the dry weight of the soil. See also **OPTIMUM MOISTURE** and **MOISTURE, PCF**.

MOISTURE-DENSITY CURVE - the curve showing the relationship between “dry unit weight” (density) and “moisture content” (water content) of a soil for a given compactive effort. The Maximum Density (Maximum Unit Weight) and Optimum Moisture are obtained from the curve.

MOISTURE, PCF - the amount of moisture determined using the nuclear gauge expressed in pounds per cubic foot.

NUCLEAR REGULATORY COMMISSION (NRC) – the NRC is the federal agency responsible for the regulation of radioactive materials.

OPTIMUM MOISTURE - moisture content in a soil at which a specified amount of compaction will produce the Maximum Dry Density.

PERCENT COMPACTION - the ratio, expressed as a percentage of the in-place unit weight of a soil to the Maximum Unit Weight obtained in a laboratory or field compaction test.

PROBE - the rod which contains the radioactive source which is inserted into the material to be tested.

PULVERIZED HOT MIX ASPHALT (HMA) - see **HMA Aggregate Base**.

ROADBED - the portion of the roadway between the outside edges of finished shoulders, or the outside edges of berms, back of curbs, or gutters, when constructed.

SATURATION - the moisture content at which all voids in soil mass are filled with water.

SCALER - the electronic module in the nuclear density gauge which records and displays the Counts/Minute (test reading) when running standards or tests.

SETTLEMENT - decrease in elevation of the surface of an embankment due to consolidation of soil within the embankment, generally resulting from its own weight, over a period of time following construction.

SOIL - unconsolidated mineral matter at or near the surface of the earth.

SOURCE - the radioactive material sealed in the gauge.

STABILIZATION - a recycling method used to improve the stability and bearing capacity of HMA material by admixing hot bitumen in-place and compacting.

STANDARD BLOCK - a polyethylene block which is used daily to field calibrate (standardize) the nuclear gauge.

STANDARD COUNT - the Counts/Minute ran and recorded daily on the Standard Block. The Standard Count is sometimes referred to as the Operating Standard.

SUBBASE - the layer of granular material placed on the subgrade as a part of the pavement structure.

SUBGRADE - the portion of the earth grade upon which the pavement structure is constructed.

TEMPLATE (SCRAPER PLATE) - a metal plate used to prepare the test site. It is used to guide the drill rod in preparing a hole for the source rod for direct transmission measurements.

TEST COUNTS - the amount of radiation detected by the gauge for a moisture or density test.

UNITED STATES DEPARTMENT OF TRANSPORTATION (U.S. DOT) – federal agency that regulates the transportation of nuclear density gauges.

VOIDS - spaces between individual soil particles occupied by air and/or water.

WET DENSITY - the total weight of a unit volume of material. This includes the weight of solids plus the weight of water.

WET MAXIMUM DENSITY - Wet Density (unit weight) of a material obtained by a specified amount of compaction at the existing or modified moisture content.

B. CHECKLIST FOR THE ONE-POINT T-99 TEST

Checklist for the One-Point T-99 Test	
1.	Obtain sample (approximately 3500 grams).
2.	Break up the sample by working it through the ¼ inch screen.
3.	Check moisture content, which should be within a range from optimum to 4.0 percent below optimum at the start of the test.
4.	Assemble the Proctor mold.
5.	Place the mold on the pounding block.
6.	Place a layer of soil in the mold (enough to fill the mold one-third full after compaction).
7.	Compact this first layer by 25 evenly distributed rammer blows.
8.	Place a second layer of soil in the mold (enough to fill it two-thirds full after compaction).
9.	Compact the second layer by 25 evenly distributed rammer blows.
10.	Place a third layer of soil in the mold (enough so that after compaction, it will extend from ¼ to ½ inch above the top of the mold).
11.	Compact this third layer by 25 evenly distributed rammer blows.
12.	Remove the collar.
13.	Use the strike-off bar to trim the sample even with the top of the mold.
14.	Remove the base plate.
15.	Weigh the mold and sample.
16.	Remove the soil from the mold.
17.	Obtain a moisture sample from the center of the soil sample. (Required when the moisture content has been manipulated).
18.	Determine Moisture % and Compacted Soil Wet, pcf.
19.	Use the One-Point T-99 Chart to determine Maximum Density and Optimum Moisture.
20.	Record the test results on Form 0582B.

C. CHECKLIST FOR THE AASHTO T-99 TEST

Checklist for the AASHTO T-99 Test	
1.	Obtain sample (approximately 5000 grams).
2.	Break up the sample by working it through the $\frac{1}{4}$ inch screen.
3.	Check moisture content, which should be approximately 4.0 percent below optimum at the start of the test.
4.	Assemble the Proctor mold.
5.	Place the mold on the pounding block.
6.	Place a layer of soil in the mold (enough to fill the mold one-third full after compaction).
7.	Compact this first layer by 25 evenly distributed rammer blows.
8.	Place a second layer of soil in the mold (enough to fill it two-thirds full after compaction).
9.	Compact this second layer by 25 evenly distributed rammer blows.
10.	Place a third layer of soil in the mold (enough so that after compaction it will extend from $\frac{1}{4}$ to $\frac{1}{2}$ inch above the top of the mold).
11.	Compact this third layer by 25 evenly distributed rammer blows.
12.	Remove the collar.
13.	Use the strike-off bar to trim the sample even with the top of the mold.
14.	Remove the base plate.
15.	Weigh the mold and sample.
16.	Remove the soil from the mold.
17.	Obtain a moisture sample from the center of the soil sample.
18.	Determine the Moisture %.
19.	Compute compacted soil wet, pcf (Maximum Density, pcf, Form 0582B)
20.	Thoroughly break-up the remaining portion of the molded specimen by working it through the screen.
21.	Recombine with the original sample and mix thoroughly.
22.	Add approximately 2 percent moisture and mix thoroughly.
23.	Reassemble the mold and repeat steps 5 through 22. This process will need to be repeated at least three times.
24.	Plot moisture content versus dry density for each data set.
25.	Connect the graph points for all tests with a smooth parabolic curve.
26.	Determine the Maximum Density, pcf and Optimum Moisture content.

D. CHECKLIST FOR THE ONE-POINT MICHIGAN CONE TEST

Checklist for the One-Point Michigan Cone Test	
1.	Obtain sample (approximately 3500 grams).
2.	Sample must have a moisture content between 5.0 percent and optimum.
3.	Place enough soil in the cone to fill it one-third full after compaction.
4.	Pound the cone 25 times or more on the pounding block, striking it sharply.
5.	Place enough soil in the cone to fill it two-thirds full after compaction.
6.	Pound the cone 25 times or more.
7.	Fill the cone completely with soil.
8.	Pound the cone 25 times or more.
9.	Completely fill the cone with soil.
10.	Pound the cone at least 10 times.
11.	Repeat steps 9 and 10 until no more consolidation occurs.
12.	Weigh the cone and sample.
13.	Check for maximum consolidation by the 20/10 Rule .
14.	Level off the material at the top of the cone with the stopper or straight-edge.
15.	Weigh the cone and sample.
16.	Empty the cone on the block or in a pan by striking the cone on the open end.
17.	Obtain moisture sample from the center of the cone. (required when the moisture content has been manipulated)
18.	Determine sample moisture content and Compacted Soil Wet, pcf.
19.	Use the One-Point Cone Chart to determine Maximum Density and Optimum moisture.
20.	Record the results on Form 0582B.

E. CHECKLIST FOR THE MICHIGAN CONE TEST

Checklist for the Michigan Cone Test	
1.	Obtain sample (approximately 3500 grams).
2.	Sample moisture content should be within a range of 5.0 percent to just short of saturation. Pound a series of cones at different moisture contents within this range to determine the Maximum Density. The Maximum Density is the highest value obtained in this series.
3.	Place enough soil in the cone to fill it one-third full after compaction.
4.	Pound the cone 25 times or more on the pounding block, striking it sharply.
5.	Place enough soil in the cone to fill it two-thirds full after compaction.
6.	Pound the cone 25 times or more.
7.	Fill the cone completely with soil.
8.	Pound the cone 25 times or more.
9.	Completely fill the cone with soil.
10.	Pound the cone at least 10 times.
11.	Repeat steps 9 and 10 until no more consolidation occurs.
12.	Level off the material at the top of the cone with the stopper or straight-edge.
13.	Weigh the cone and sample.
14.	Empty the cone on the block or in a pan by striking the cone on the open end.
15.	Obtain a moisture sample from the center of the cone.
16.	Determine the moisture content.
17.	Compute the Maximum Density.
18.	Three tests should be made within the moisture range as explained in step 2. The highest test result is the Maximum Density, pcf.
19.	When water is added be sure to mix the sample thoroughly.
20.	Record the test results on Form 0582B.

F. CHECKLIST FOR THE MICHIGAN MODIFIED T-180 TEST

Checklist for the Michigan Modified T-180 Test	
1.	Perform the In-Place tests in the "Asphalt Mode."
2.	Obtain the Maximum Density sample from the In-Place test location.
3.	The mold is pounded at existing in-place moisture.
4.	Make sure the Proctor mold is assembled correctly.
5.	The pounding block should be placed on firm ground or pavement.
6.	Place a layer of material in the mold (enough to fill the mold one-fifth after compaction).
7.	Compact the layer with 25 evenly distributed blows using the 10-pound rammer.
8.	Place the second, third and fourth layers in the mold, each layer filling one-fifth of the volume of the mold, and compact each layer with 25 evenly distributed blows.
9.	Place the fifth layer in the mold. Enough material is used so that after compaction, the material will extend from $\frac{1}{4}$ to $\frac{1}{2}$ inch above the top of the mold.
10.	Compact the fifth layer with 25 evenly distributed blows.
11.	Remove the collar.
12.	Use the strike-off bar to trim the excess material even with the top of the mold.
13.	Remove the bottom plate from the mold.
14.	Weigh the sample and mold to the nearest gram.
15.	Complete the computations through Column H (Compacted Soil Wet, PCF) on Form 0582B.
16.	The resultant value from Column H is the Maximum Density (wet) and should also be recorded in Column I (Maximum Density, PCF).
17.	This test is normally used on In-Place recycling jobs. The material changes frequently for this type of work, and therefore, the Maximum Density will have to be re-established more often and also when the moisture changes more than ± 1.5 percent.

G. CHECKLIST FOR USE OF THE NUCLEAR GAUGE

Checklist for Use of the Nuclear Gauge Troxler Model 3440	
1.	Check the ID number on the gauge book and the standard block and be sure they match the ID number on the gauge. Gauge books and standard blocks are not interchangeable. Ensure gauge has been calibrated within the last year.
2.	Turn the gauge on and allow a 20 minute warm-up before running standards.
3.	Record Chart Standards for Density and Moisture.
4.	Run Operating Density and Moisture Standards <u>daily</u> and record.
5.	Select the test location and prepare the test site.
6.	Run the Density and Moisture tests and record the test readings.
7.	Record the Wet Density, PCF and Moisture, PCF.
8.	Record the Dry Density, PCF and Moisture, %.
9.	Record the Density and Moisture Counts.
10.	Record and program the gauge with the correct Maximum Density, PCF.
11.	Record the Percent of Compaction.
12.	When finished running a test, lock and return the gauge to the transport case in the pickup truck.
13.	Rechargeable batteries have a memory and repeated needless charging will shorten the battery life. Do not recharge batteries unless <Batteries Low!> is visible on the display. For a full charge, re-charge the gauge for 16 hours. A full charge should last from four to six weeks.
14.	Report malfunctions promptly to the Area Density Specialist.
15.	Gauge users are not authorized to make field repairs or perform gauge maintenance. Only Statewide and Area Density Specialists are permitted to maintain or repair gauges.
16.	Follow all safety rules and regulations.
17.	Transport the gauge according to US DOT regulations.
18.	When the gauge is left unattended in a vehicle, both the vehicle and the gauge <u>must</u> be locked.

H. CHECKLIST FOR USING NUCLEAR GAUGE

Checklist for Use of the Nuclear Gauge InstroTek 3500 Xplorer 2	
1.	Check the ID number on the gauge book and the standard block and be sure they match the ID number on the gauge. Gauge books and standard blocks are not interchangeable. Ensure gauge has been calibrated within the last year.
2.	Turn the gauge on and allow a 20 minute warm-up before running standards.
3.	Record Chart Standards for Density and Moisture.
4.	Run Operating Density and Moisture Standards <u>daily</u> and record.
5.	Select the test location and prepare the test site.
6.	Run the Density and Moisture tests and record the test readings.
7.	Record the Wet Density, PCF and Moisture, PCF.
8.	Record the Dry Density, PCF and Moisture, %.
9.	Record the Density and Moisture Counts.
10.	Record and program the gauge with the correct Maximum Density, PCF.
11.	Record the Percent of Compaction.
12.	When finished running a test, lock and return the gauge to the transport case in the pickup truck.
13.	Rechargeable batteries have a memory and repeated needless charging will shorten the battery life. Do not recharge batteries unless <Recharge Battery> is visible on the display. For a full charge, recharge the gauge for 16 hours. A full charge should last from four to six weeks.
14.	Report malfunctions promptly to the Area Density Specialist.
15.	Gauge users are not authorized to make field repairs or perform gauge maintenance. Only Statewide and Area Density Specialists are permitted to maintain or repair gauges.
16.	Follow all safety rules and regulations.
17.	Transport the gauge according to US DOT regulations.
18.	When the gauge is left unattended in a vehicle, both the vehicle and the gauge <u>must</u> be locked.

I. SPECIAL NOTES ON WEIGHING PROCEDURES

Special Notes on Weighing Procedures	
1.	Check the weights of cones and molds periodically.
2.	A balance or scale conforming to AASHTO M 231, Class G20 must be used for weighing Proctor molds or cones.
3.	Use the balance furnished with the “Speedy” kit for weighing moisture samples.

J. CHECKLIST FOR THE CALCIUM CARBIDE GAS PRESSURE METER

Checklist for the Calcium Carbide Gas Pressure Meter ("SPEEDY" Moisture Tester)	
1.	Setup SPEEDY before cone/T-99 test is started.
2.	Clean cap with cloth.
3.	Clean SPEEDY body <u>only</u> with brush that is provided.
4.	Put three scoops of calcium carbide into SPEEDY tester body.
5.	Obtain sample for moisture from center/middle of mold.
6.	Always screen cohesive and aggregate sample through a ¼ inch screen before weighing sample.
7.	Weigh full sample (26 g or 20 g) for granular material or half sample (13 g or 10 g) for cohesive material.
8.	Place material in the cap.
9.	Hold SPEEDY horizontally when placing the cap into the body to prevent the soil sample and calcium carbide from mixing before the cap is fully sealed.
10.	Hold the SPEEDY upright and tap the side of the body with heel of hand to knock material down from cap.
11.	Shake and rotate the SPEEDY to create pressure.
12.	Hold SPEEDY horizontally at eye level to obtain reading on dial.
13.	Continue shaking and reading until the needle stops moving. To verify that the needle has stopped moving, you achieve three consecutive readings of the same value.
14.	Read the dial to the nearest tenth and take the reading to the conversion chart to obtain the oven-dry moisture content. When working with cohesive soils, the reading on the dial must be multiplied by two before going to the conversion chart.
15.	Record oven-dry moisture content in column B (moisture %) under Determination of Maximum Density on form 0582B.
16.	Empty SPEEDY downwind and away from face. Do not tap the body with the cap.
17.	Clean cap with cloth and body with brush before putting SPEEDY back in box.

K. MINIMUM FREQUENCY OF TESTING

For density control of embankment, subbase, base course and HMA surfaces, a sufficient number of tests should be made to ensure that the specified results are being obtained. The frequency of testing will vary with the project, the placement operation and the material being used. For a job where compaction is relatively easy to obtain, the material is reasonably uniform and the compacting methods are consistent, a minimum number of tests are needed for acceptance. The minimum frequency of tests needed under these relatively ideal conditions follow. Most operations will require more tests for proper control.

Specifications require each material to meet the required density and moisture content.

Specification/Material	Test Guide	Frequency-See Notes below
205 Subgrade (includes stabilized)	Density	1 test per 500 feet per width of 24 feet or less
205 Embankment	Density	1 test per 1000 cubic yards of material-see note 2
301 Subbase	Density	1 test per 500 feet per width of 24 feet or less
Backfill	Density	1 test per 300 cubic yards of material-see note 2
302 Aggregate Base Course	Density	1 test per 500 feet per width of 24 feet or less
501 HMA Mixtures	Density	1 test per 1000 feet per width of 24 feet or less
307 Shoulders	Density	1 test per 1000 feet each side
Sleeper Slab	Density	1 test in the footprint per bridge approach or per stage for part width construction
307 Trenching	Density	1 test per 1000 feet each side

Notes

1.) It must be emphasized that project conditions normally require more frequent testing for proper compaction control. In addition, the specifications require that each layer must meet compaction requirements before the succeeding layer is placed.

2.) Regardless of the volume of material placed, a minimum of one test must be taken for each layer.

L. EQUIPMENT FURNISHED IN DENSITY TEST KITS

- 1 Electronic Scale
- 1 T-99 rammer
- 1 T-180 rammer
- 1 Proctor mold
- 1 Strike-off bar
- 1 Michigan Cone with stopper
- 2 10 inch by 10 inch pans
- 1 12 inch spoon
- 1 One-Point Michigan Cone chart
- 1 One-Point T-99 chart
- 1 "Speedy" Moisture Tester kit
- 1 Density Testing and Inspection Manual
- 1 8 inch by 8 inch by 10 inch hardwood pounding block
- 1 18 inch by 18 inch screen with $\frac{1}{4}$ inch mesh
- 1 Nuclear gauge, gauge transport book, and standard block