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7.0 Compaction Testing of Soil Using the Sand Cone Method

7.1 Procedure Using the Sand-Cone Method

The procedure outlined here follows principles of ASTM D 1556 and AASHTO T-272. This method may be used for soil or granular material.

Calibration of the Sand

Use only dry free-flowing sand. Empty the sand-cone apparatus completely before each filling. Place the sand-cone device in an upright position on a level surface free from vibrations caused by nearby construction equipment. Use the following procedure:

1. Weight the sand-cone apparatus. See Figure 7-6. Close the value of the sand-cone apparatus and fill the upper cone with sand.
2. Open the valve and allow the jar and lower cone to fill while keeping the upper cone filled with sand. Do not move or jar the apparatus during filling.
3. Close the valve when the jar and lower cone are filled.
4. Remove sand from upper cone.
5. Weigh the filled apparatus and record on Line 13 of Form C-88M (C-88).
6. Calculate the unit dry weight of the sand, following directions given in Lines 14 through 17, Form C-88M (C-88). (After the jar is filled and the valve closed, the apparatus may be moved about and the sand weight need not be rechecked before using.)

Testing Procedure

1. Invert and firmly seat sand-cone apparatus on area leveled for testing. Thin plastic which will conform to irregularities and can be used on the surface under the sand-cone apparatus to facilitate later removal of the sand.
2. Mark the surface of the soil around the edge of the seated cone to insure reseating the same position.
3. Open the valve and allow cone to fill with sand.
4. Close valve and weigh the apparatus and remaining sand, and record on Line 18 of Form C-88M (C-88).
5. Brush away and discard the sand, or if plastic is used, lift the plastic and discard sand.
6. Dig a hole in center of area covered by the upper cone. A 100mm (4-inch) post-hole auger serves as a satisfactory tool for cutting the hole. Use a pan with a hole in it to gather the soil up. Other useful tools for cutting and collecting are chisel, hammer, large spoon, and small paint brush. Cut the hole as smoothly as possible. Avoid disturbing adjacent soil.
7. Remove approximately 3.0 kg (6 pounds) of soil from the hole and collect in a container of known weight. Make sure all soil from the hole is collected in the container. Loss of soil will affect the accuracy of the test.
8. Weigh the container and soil, and record on Line 1 of Form C-88M (C-88). Record weight of container on Line 2. Subtract Line 2 from
Line 1 and record on Line 3. This is the weight of soil removed from the hole.

9. Place the upper cone of sand-cone apparatus over the hole in the same position used in filling the upper cone.

10. Open the valve and allow auger hole and upper cone to fill with sand. After hole and upper cone are filled, close the valve.

11. Weigh the sand-cone apparatus and remaining sand. Record on Line 20 of Form C-88M (C-88).

12. Calculate volume of the hole by following the procedure indicated in steps 20 through 23, Form C-88M (C-88).
7.2 One Point Proctor Test

This is the same procedure outlined in Section 4.4 (Step 4 of Procedures).

1. Pass the soil obtained from the hole through a 4.75mm (No. 4) sieve when using the penetration resistance method and 19 mm (3/4 inch) sieve when using other drying methods. Do this as quickly as possible, protected from sun and wind, to prevent loss of moisture. If it is apparent by inspection that all or most of the material will pass a 4.75mm (No. 4) sieve or 19.0mm (3/4 inch) sieve it is not necessary to pass the material through the sieve.

    a. If the soil is highly plastic and is high in moisture, it may be difficult to pass the material through a 4.75mm (No. 4) sieve or 19 mm (3/4 inch) sieve. To determine if a soil meets this condition, take a small portion of the soil and roll it between the fingers of one hand and the palm of the other. If the soil can be rolled into a thread with diameter less than 3.18mm (1/8 inch) the soil moisture is considered to be in excess of the plastic limit and need not be passed through the 4.75mm (No. 4) sieve or 19 mm (3/4 inch sieve).

2. Weigh the material retained on the 4.75mm (No. 4) sieve or 19mm 3/4” sieve. If the weight is more than 1/10 the total sample, record on Line 29 of Form C-88M (C-88). If the weight is less than 1/10 the total sample discard the stone and do not record the weight.

3. Record the weight of the proctor cylinder on Line 5 of Form C-88M (C-88).

4. Form a specimen by compacting the prepared soil in the 102mm (4-inch) diameter mold, volume 0.000943m³ (1/30 cubic feet), included in the compaction control kit, in 3 equal layers to give a total compacted depth of about 127mm (5 inches). (See Figure 4-6 for recommended loose lifts). Compact each layer by applying 25 uniformly-well-distributed blows from the 2.5 kg (5-1/2 pound) rammer dropping from a height of 305mm (12 inches) above the elevation of the soil. Ensure that the cylinder is resting on a uniformly rigid foundation during compaction. Usually a concrete block is used.

*NOTE:* It is possible for some tests that the soil passing the sieve is not of sufficient quantity to fill the cylinder mold. In this case, more soil can be obtained near the hole, so that the soil likely will be the same type and moisture as that obtained from the hole. This soil should be passed through the sieve, but need not be weighed.

5. Remove the collar and strike off the soil level with the cylinder. If voids are evident, use fine material to completely smooth the surface.

6. Weigh the cylinder and soil and record weight on Line 4 of Form C-88M (C-88).

**Warning:** A soil cannot be tested for compaction without performing a one point proctor.
7.3 Penetration Resistance Determination

Determine the resistance of the soil to penetration by use of the soil penetrometer, contained in the compaction kit, with the attached needle of known end area, and using the following procedure unless percent moisture is determined by drying methods. **Warning:** Use drying or nuclear method to determine percent moisture in lieu of the penetration resistance method when performing a one (1) point proctor test. Only use the penetration resistance method as a last resort. This method is being misused.

1. Place the mold containing the soil on a smooth space between your feet.
2. Hold the penetrometer in a vertical position over the sample. Force the needle into the sample at the rate of 13mm (0.5 inch) per second for a distance of not less than 75mm (3 inches). Use a needle size that will give readings between 90N - 330N (20 and 75 pounds), except that for the 32.3mm² (1/20-square inch) needle, readings above 270N (60 pounds) shall not be used.
3. Repeat this process at least two more times, insuring that the penetrations are away from the edge of the mold, and spaced not to interfere with one another.
4. Divide the average penetrometer reading by the end area of the penetration needle and record on Line 9, Form C-88M (C-88) the resulting value as the penetration resistance of the soil, expressed in mega-pascals (pounds per square inch).
7.4 Selection of Moisture-Density Curve

Either a moisture-density curve prepared by the Laboratory for an individual sample or a typical curve selected from the set of typical moisture-density curves may be used for determining the percent compaction of the soil. Typical moisture density curves have been prepared in the form of a chart and also in the form of a slide rule. The chart is illustrated by 7-4M (7-4) and the slide rule by Figure 7-3. The curves on the rotating disc of the slide rule provide the same data as those shown by the chart. Each embankment control kit is equipped with a circular slide rule.

Using a Circular Slide Rule

To select a typical moisture-density curve, the weight per cubic meter (cubic foot) of compacted wet soil and the average penetration resistance for the soil sample must be determined. These determinations are made on form C-88M (C-88) lines 5 through 9. To select the best typical moisture-density curve representing the soil sample, refer to Figures 7-2M (7-2) and 7-3 and proceed as follows:

1. Pull out the slide of the slide rule and set the short tangent line on the wet weight scale at the wet weight recorded on Line 7 under (water added) of Form C-88M (C-88). For this example use, 2067 kg/m³ (129 pounds per cubic foot).

2. Rotate the chart until the short tangent line intersects a wet weight curve near the peak. Eliminate from consideration all curves which lie completely below this line. Note that the short tangent line intersects the wet weight curve at two points, one on the wet (right) side of the peak, and on the dry (left) side.

3. Again rotate the chart until the cross formed by the short tangent line of the slide and the center radial line of the window lies on the wet weight curve, on the dry (left) side of the peak. Note the moisture content where the center radial line intersects the moisture content scale.

4. Set the short tangent line at the mega-pascals (pounds per square inch) penetration recorded on Line 9 of Form C-88M (C-88). This example uses 5.516 MPa (800 pounds per square inch).

5. Rotate the chart until the penetration resistance curve is under the intersection of the short tangent line and the center radial line.

6. Note the moisture content where the center radial line intersects the moisture content scale.

7. Determine the difference between the two moisture contents.

8. Repeat the procedure outlined in (3) for the wet (right) side of curve, and for the wet and dry side of adjacent curves. Do not select a curve for which this difference is greater than 1-1/2 percent. Lines are inscribed on the window of the slide rule at 1-1/2 percent on either side of the center radial line as shown in Figure 7-3. These lines may be used to determine whether or not the moisture content differences as determined above fall within the 1-1/2 percent and their use should speed up the selection of the proper curve.

9. In this example, the differences between the moisture contents found by the moisture density and by the penetration resistance curves were determined for moisture-density curves, K, L and M. The moisture and moisture differences for this example follow:
10. The curve which is most representative of the soil is the one that gives the smallest difference in moisture from the wet weight curve compared with the moisture from the penetration resistance curve. The smallest difference in columns 4 and 6 is 0.2 for this example. Therefore, Curve M is the most representative curve.

11. After the curve is selected, read and record the moisture from the wet weight reading, Line 7, Figure 7-2M (7-2). In this example the wet weight to be used for moisture determination is 1866 kg/m³ (116.4 pounds per cubic foot), and the resulting moisture from the typical curve slide rule is 9.8 percent.

12. Record the following on Form C-88M (C-88).

For this example:
A. Letter designation of curve (Lines 10,11 and 26 ) ......................... M
B. Optimum moisture (Line 10) .......................... 15.8
C. Moisture from wet weight curve (Line 11).............................................. 9.8
D. Amount above as below optimum moisture (Line 12).......................... 6.0 below
E. Maximum dry weight (Line 26)........................................... 1794 kg m³(112 lb/ft³)

Using Plotted Ohio Typical Curves
To select a representative typical curve, the plotted typical curves, the weight per cubic meter (foot) of compacted wet soil and the average penetration resistance for a soil sample must be known. These determinations are made according to directions in Lines 4 through 9, Form C-88M (C-88). For the purpose of the following example to illustrate how the plotted typical curves are used, start with the data given in Steps 7 and 9, Figure 7-2M (7-2), which is:

Line 7
........ Weight/m³ compacted wet soil ......... 1866kg/m³
........ Weight/cu. ft. compacted wet soil (116.4 lbs/ft³)

Line 7 (Water added)
........ Weight/m³ compacted wet soil ......... 2067kg/m³
........ Weight/cu ft. compacted wet soil .................
(129.0 lbs./ft³)

Line 9 (Water added)
........ Average penetration resistance ........ 5.516 MPa
........ Average penetration resistance ........ 800 lbs./in²
For this example, the soil was so dry that it was not possible to obtain a penetration resistance reading when it was first compacted in the 0.000943m³ (1/30 cubic foot) cylinder mold, Line 7. It was necessary to remove
the soil from the cylinder mold, add water until the moisture content was near optimum, and recompact in the cylinder mold. Use the figures 2067 kg/m³ (129.0 pounds per cubic foot) and 5.516 MPa (800 psi.) determined after adding water, and proceed as follows to select a representative typical curve:

1. Draw a horizontal line through the 5.516 MPa (800 psi.) reading on the plotted typical penetration resistance curves, Figure 7-4M (7-4). Note that this line intersects all curves.

2. Draw a horizontal line through the 2067 kg/m³ (129.0 pound per cubic foot) reading on the plotted typical wet weight curves, as shown in Figure 7-4M (7-4). Note that this line lies above and does not intersect curves N through Z. Therefore, none of these curves is representative of the soil being checked and may be eliminated from consideration.

3. Note that this horizontal line at 2067 kg/m³ (129.0 pounds per cubic foot) intersects curves D through J at locations considerably drier than optimum, and at moistures for which the penetration resistance is considerably higher than 5.516 MPa (800 psi.). Therefore, none of these curves is representative of the soil being checked.

4. Note that this horizontal line at 2067 kg/m³ (129.0 pounds per cubic foot) intersects curves K, L and M on both the wet and dry side of the peak at moistures, near optimum, for which penetration resistance values are near 5.516 MPa (800 psi.). Therefore, one of these three curves is representative.

5. To determine which of the three curves is most representative, compare the moisture determined by the wet weight with the moisture determined by the penetration resistance. The moistures, tabulated for this example, are as follows:

<table>
<thead>
<tr>
<th>Curve</th>
<th>Moisture from Pen. Resist Curve (Dry) Side</th>
<th>Moisture from Left (Dry) Side</th>
<th>Difference between Columns 2 &amp; 3</th>
<th>Moisture from Right (Wet) Side</th>
<th>Difference between Columns 2 &amp; 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>13.9</td>
<td>12.0</td>
<td>1.9</td>
<td>18.8</td>
<td>4.9</td>
</tr>
<tr>
<td>L</td>
<td>14.7</td>
<td>13.8</td>
<td>0.9</td>
<td>18.5</td>
<td>3.8</td>
</tr>
<tr>
<td>M</td>
<td>15.7</td>
<td>15.5</td>
<td>0.2</td>
<td>18.0</td>
<td>2.3</td>
</tr>
</tbody>
</table>

6. The curve that is most representative of the soil is the one that gives the smallest difference in moisture from the wet weight curve (column 3 or 5) compared with the moisture from the penetration resistance curve. The smallest difference in columns 4 and 6 is 0.2 for this example. Therefore, Curve M is the most representative curve.

7. After the curve is selected, read and record the moisture from the wet weight reading, Line 7, Figure 7-2M (7-2). In this example, the wet weight to be used for moisture determination is 1866 kg/m³ (116.4 pounds) per cubic foot and the resulting moisture from typical Curve M is 9.8 percent.
8. Record the following on Form C-88M (C-88):

A. Letter designation of curve (Lines 10, 11 and 26 or 34) M
B. Optimum moisture (Line 10) 15.8
C. Moisture from wet weight curve (Line 11) 9.8
D. Amount above as below optimum moisture (Line 12) 6.0 below
E. Maximum dry weight (Line 26) 1794kg/m³ (112.0 lb/c.f.)
7.5 Calculation of Compaction

Having determined the wet weight of the in-place material, the typical curve, and the moisture content, calculate the percent compaction as follows.

When Sample Contains
No Stone on the 4.75mm (No. 4) Sieve or 19.0mm (3/4") Sieve

1. Follow directions given in Lines 24 through 27, Form C-88M (C-88), and record data.
2. For the example shown in Figure 7-2M (7-2), the percent compaction is 100.7 (100.9) percent. The difference is due to rounding in the separate calculations.

When Sample Contains
Stone on the 4.75mm (No. 4) Sieve or 19mm (3/4") Sieve

1. When the material retained on the 4.75mm (No. 4) or 19mm (3/4 inch) sieve exceeds 10 percent by weight Line 30 on C-88M (C-88), then follow the directions on Lines 28 through 38. See Figure 7-5M (7-5).
2. Inspect the material retained on the 4.75mm (No. 4) sieve to determine which of the following classifications most nearly represent the material: limestone, gravel, sandstone and sandy shale. Circle the representative material and average specific gravity listed at the bottom of Form C-88M (C-88).
7.6 Check for Specification
Compaction Requirements

These requirements are as follows:

**Embankment Soil Compaction Requirements**

<table>
<thead>
<tr>
<th>Maximum Laboratory Dry Wt.</th>
<th>Minimum Compaction requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/m³</td>
<td>lbs/cu. ft.</td>
</tr>
<tr>
<td>1440-1680</td>
<td>90-104.9</td>
</tr>
<tr>
<td>1681-1920</td>
<td>105-119.9</td>
</tr>
<tr>
<td>1921</td>
<td>120 and more</td>
</tr>
</tbody>
</table>

Soil subgrade with maximum laboratory dry weight of 1600 - 1680 kg/m³ (100-105 pounds per cubic foot) shall be compacted to not less than 102 percent of maximum dry density. All other soil subgrade shall be compacted to not less than 100 percent of maximum dry density.

1. Record the minimum compaction requirements and the condition which applies (Embankment or subgrade) in the space provided in the heading of Form C-88M (C-88).
2. If the compaction from the test is equal to or greater than specification requirements, write “yes” in the space provided at the bottom of Form C-88M (C-88).
3. If the compaction from the test is less than specification requirements, write “no” in the space provided, and require the Contractor to correct the deficiency. Check or note action taken at the bottom of Form C-88M (C-88).
7.7 Check for Specification Moisture Requirements

The specifications were changed in 1993. These requirements are from 203.11 of the specifications and are as follows:

203.11 Moisture Control. “Embankment and subgrade material containing excess moisture shall be required to dry prior to or during compaction to a moisture content not greater than that needed to meet the density requirements, except that for material which displays pronounced elasticity or deformation under the action of loaded rubber tire construction equipment, the moisture content shall be reduced to secure stability. For subgrade material, these requirements for moisture shall apply at the time of compaction of the subgrade. Drying of wet soil shall be expedited by the use of plows, discs, or by other approved methods when so ordered by the Engineer.”

Purpose

It is the purpose of this specification requirement to insure stable embankments. This is the reason for limiting moisture content for soil in embankment. Experience has shown that some soil types, particularly silty soils with low plasticity can have unsatisfactory stability even though moisture contents of such soil is near optimum. In these cases the moisture content should be reduced to secure stability and still meet the density requirements.

1. If the moisture content of the soil allowed the Contractor to obtain the specification density and it produced a stable embankment write “yes” at the bottom of Form C-88M (C-88).
7.8 Check Using Zero Air

**Voids Formula**

The zero air voids method is a convenient means of checking compaction test results for possible errors.

1. The zero air voids formula is as follows:

\[
W(\text{max}) = \left[ \frac{1000}{D} - \frac{1}{G} \right] \times 100 \quad \text{Metric}
\]

\[
W(\text{max}) = \left[ \frac{62.4}{D} - \frac{1}{G} \right] \times 100 \quad \text{English}
\]

Where:

- \(W(\text{max})\) = maximum water content theoretically possible at density \(D\)
- \(D\) = dry weight of soil (from Line 25 or 36 of Form C-88M (C-88))

G = 2.67 = the average specific gravity for Ohio soils

Substituting 2.67 for \(G\), the formula becomes

\[
W(\text{max}) = \left[ \frac{1000}{D} - .375 \right] \times 100 \quad \text{Metric}
\]

\[
W(\text{max}) = \frac{62.4}{D} - .375 \times 100 \quad \text{English}
\]

(2) If the moisture content from the compaction test, Line 11, Form C-88M (C-88) is greater than \(W(\text{max})\) an impossible condition is indicated: that is, there is a greater volume of water in the material at this density, than possibly could be contained in the voids at this density. Therefore, if moisture from the compaction test is higher than \(W(\text{max})\) an error in the test is indicated, and the test procedures and calculations need to be checked.

(3) Check all tests by the zero air voids method.
7.9 Check Using Zero Air Voids Curve

A curve showing the relation of the maximum theoretical moisture $W(\text{max})$ to the dry density of soil (D) having a specific gravity of 2.67 is shown in Figures 7-7M (7-7). This chart may be used instead of the formula for checking water content at zero air voids. To determine the maximum theoretical moisture from this chart, proceed as follows:

1. Plot the dry density shown on Line 25 or 36 of Form C-88M (C-88) on the vertical scale of the curve. (Example, 1807 kg/m³ (113.0 lb/ft³), Figures 7-2M (7-2) from Line 25.
2. Draw a horizontal line from this point to the intersection of the zero air voids curve closest to the dry weight scale.
3. Draw a vertical line from this point to the horizontal scale at the bottom of the chart. The moisture obtained from the horizontal scale is the maximum theoretical moisture that the soil can contain, Figure 7-2M (7-2). (Example, 17.8 percent).
4. Compare this moisture with the moisture from the compaction test shown on Line 11, Figure 7-2M (7-2). (Example, 9.8 percent).
5. If the moisture shown on Line 11 is greater than the moisture determined by the zero air voids check, an error in the test is indicated, and the test procedures and calculations need to be checked. For this example, 9.8 is not greater than 17.8, and, therefore, the zero air voids check does not indicate an error in test results.
6. Record $W(\text{max})$ from zero voids curve in the margin of Form C-88M (C-88). (Example: $W(\text{max}) = 17.8\%$

NOTE: This curve is based on a soil specific gravity of 2.67. At higher specific gravities this curve will shift to the right allowing higher $W(\text{max})$ moistures. Recent evaluation of data relative to specific gravities, indicate it is not unreasonable to have moisture content 1% higher than the zero air voids curve.

If there is absolute assurance that test procedures are correct, tests may be accepted if the % moisture is not more than 1% higher than the $W(\text{max})$ indicated by the curve.
7.10 Precautions to Prevent Errors

Because of the many operations to be performed in a compaction test, and because small errors may accumulate to give a large error in the final result, every precaution must be taken with each operation of the test to insure accuracy in the final result. Some precautions to avoid errors that are frequently made are as follows:

1. Insure that the density-cone apparatus is empty and dry at the start of the test.
2. Insure that the cylinder mold is placed on a firm foundation while making the test.
3. Make the penetration needle is in a vertical position when making the penetration resistance test. Also the depth and rate of penetration as given in the directions must be used.
4. Insure that the balance is leveled, out of the wind, and moves freely. Make all weight determinations to the nearest gram (0.01 pound). Some scales may weigh to the nearest 0.1 of a gram. Usually round to nearest gram.
5. Make sure that the curve that gives the closest correlation between moisture as given by penetration resistance and moisture as given by the wet weight curve is used. Use the moisture given by the wet weight curve for all computations.
6. Check all calculations on the test for accuracy.
<table>
<thead>
<tr>
<th>Project/P.O.</th>
<th>P.O. Ind.</th>
<th>Item Code</th>
<th>Ref. Number</th>
<th>Item Code</th>
<th>Ref. Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>96(92)</td>
<td>203-10001</td>
<td>4.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test of (check which): [□] Embankment [☑] Subgrade [□] Base [□] Other

Min. Compaction Req.: 100 %

From Sta 6 + 251.4 at ___ meters 2.5 (ft) of centerline, at approx. Elevation 221.2 ft

Read: "Manual of Procedures for Earthwork"

1. Weight of wet soil & stone, if any from auger hole + weight of container
   1. = 4.944 kg
   2. = 1.973 kg
   3. = 2.976 kg (Water Added)

2. Weight of container
   4. = 6.469 kg

3. Weight of wet soil & stone, if any from auger hole (#1 less #2)

4. Weight of 0.000943 m³ compacted wet soil + weight of container
   5. = 4.503 kg

5. Weight of 0.000943 m³ container
   6. = 1.895 kg

6. Weight of 0.000943 m³ compacted wet soil (#4 less #5)

7. Density of compacted wet soil (1060 X #6)
   7. = 1.947 kg/m³

8. **Average penetration reading (3 or more tests) using __ mm² needle
   8. = ___ N

9. **Average penetration resistance (9+ end area of needle)
   9. = ___ MPa

10. Optimum moisture from Dry Weight Curve (Curve No. N )
   10. = 16.9 %

11. Moisture from Wet Weight Curve (Curve No. N ) or by drying
    11. = 15.1 %

12. Amount above or below of optimum moisture (difference #10 & #11)

13. Weight of sand + weight of density-cone apparatus
   13. = 8.324 kg

14. Weight of density-cone apparatus
   14. = 2.513 kg

15. Weight of sand in density-cone apparatus (#13 less #14)
   15. = 5.811 kg

16. Volume of density-cone apparatus (recorded on density-cone)
   16. = 0.00276 m³

17. Density of sand (#15 + #16)
   17. = 1.359 kg/m³

18. Weight of density-cone and remaining sand after cone is filled on leveled area
   18. = 7.180 kg

19. Weight of sand required to fill cone on leveled area (#13 less #18)
   19. = 1.144 kg

20. Weight of density-cone and remaining sand after filling auger hole & cone
    20. = 4.042 kg

21. Weight of sand in auger hole & cone (#16 less #20)
    21. = 3.158 kg

22. Weight of sand in auger hole (#21 less #19)
    22. = 1.934 kg

23. Volume of auger hole (#22 ÷ #17)
    23. = 0.001467 m³

Procedure when sample contains less than 1/10 total weight in stone retained on 19.0 mm or 4.75 mm sieve***

24. Density of wet soil in fill (#3 ÷ #23)
    24. = 2.029 kg/m³

25. Density of dry soil in fill ([100 x #24] ÷ (100 + #11])
    25. = 17.63 kg/m³

26. Max dry density (From Curve No. N )
    26. = 17.56 kg/m³

27. Compaction (#25 + #26 x 100)
    27. = 100.4 %

Procedure when sample contains more than 1/10 total weight in stone retained on 19.0 mm or 4.75 mm sieve***

28. Weight of Sample (#3)
    28. = 2.976 kg

29. Weight of stone removed from sample and retained on 19.0 mm or 4.75 mm sieve
    29. = 0.231 kg

30. Percent stone in sample (#29 ÷ #28 x 100)
    30. = 7.8 % OK

31. Weight of stone in one cubic meter of material (#24 x #30 ÷ 100)
    31. = ___ kg

32. Volume of stone in one cubic meter of material [#31 ÷ (Sp. Gr.* x 1000)]
    32. = ___ m³

33. Volume of wet stone in one cubic meter of material (#1.00 less #32)
    33. = ___ m³

34. Weight of wet soil in one cubic meter of material (#24 less #31)
    34. = ___ kg

35. Density of wet soil (#34 ÷ #33)
    35. = ___ kg/m³

36. Density of dry soil ([#35 x 100] ÷ #11 + #100)
    36. = ___ kg/m³

37. Compaction with stone removed (#36 ÷ #26 x 100)
    37. = ___ % OK

38. Moisture from zero air voids curve using (#25 or #36)
    38. = 19.5 %

*Average Specific Gravity Values: Limestone = 2.6; Gravel = 2.5; Sandstone and Sandy Shale = 2.2

**Use this method only as a last resort.

***Use 4.75 mm sieve for penetration method only.

Does material tested meet specification requirements for (write yes or no on each of following)

Max. dry weight YES

Moisture YES Compaction YES

Does test check zero air voids curve (check which): [☐] Yes [☑] No

Action taken by (check which): [☐] Inspector or [☑] Project Engineer

If material tested does not meet specification requirements:

[☐] Additional rolling ordered [☐] Aerating ordered [☐] Watering ordered [☐] Other

Computed By JOE COMPATION

Checked By CHARLIE DIGER

DOT-1636

---

Figure 7-1M. C-88M Example of Sand Cone Test Using Drying Method
Chapter 7.0 Compaction Testing of Soil Using The Sand Cone Method

Figure 7-1. C-88 Example of Sand Cone Test Using Drying Method
Figure 7-2M. C-88M Example of Sand Cone Test Using Penetration Resistance
Figure 7-2. C-88 Example of Sand Cone Test Using Penetration Resistance

**Average penetration reading (3 or more tests) using 1/20 in² needle**

- Test: 1. Weight of wet soil & (stone, if any) from auger hole + weight of container
- Test: 2. Weight of container
- Test: 3. Weight of wet soil & (stone, if any) from auger hole (#1 less #2)

**Average penetration resistance (#8 + end area of needle)**

- Test: 4. Weight of 1/30 ft³ compacted wet soil + weight of container
- Test: 5. Weight of 1/30 ft³ container
- Test: 6. Weight of 1/30 ft³ compacted wet soil (#4 less #5)
- Test: 7. Density of compacted wet soil (30 X #6)

**Optimum moisture from Dry Weight Curve (Curve No. M)**

- Test: 8. Optimum moisture

**Moisture from Wet Weight Curve (Curve No. M) or by drying**

- Test: 9. Moisture

**Amount above or below optimum moisture (difference #10 & #11)**

- Test: 10. Moisture

**Weight of sand + weight of density-cone apparatus**

- Test: 11. Weight of sand + weight of density-cone apparatus

**Weight of sand in density-cone apparatus (#13 less #14)**

- Test: 12. Weight of sand in density-cone apparatus

**Volume of density-cone apparatus (recorded on density-cone apparatus)**

- Test: 13. Volume of density-cone apparatus

**Density of sand (#15 + #16)**

- Test: 14. Density of sand

**Weight of density-cone and remaining sand after cone is filled on leveled area**

- Test: 15. Weight of sand required to fill cone on leveled area (#13 less #18)

**Weight of density-cone and remaining sand after filling auger hole & cone**

- Test: 16. Weight of sand in auger hole and cone (#18 less #20)

**Weight of sand in auger hole (#21 less #19)**

- Test: 17. Weight of sand in auger hole

**Volume of auger hole (#22 + #17)**

- Test: 18. Volume of auger hole

**Density of soil in fill [(100 x #24) ÷ (100 + #11)]**

- Test: 19. Density of soil in fill

**Max dry density (From Curve No. M)**

- Test: 20. Max dry density

**Compaction (#25 ÷ #26 x 100)**

- Test: 21. Compaction

**Procedure when sample contains more than 1/10 total weight in stone retained on 3/4" or No. 4 sieve***

- Test: 22. Weight of sample (3#)

**Procedure when sample contains less than 1/10 total weight in stone retained on 3/4" or No. 4 sieve***

- Test: 23. Weight of stone removed from sample and retained on 3/4" or No. 4 sieve

**Average Specific Gravity Values:**

- Limestone = 2.6; Gravel = 2.5; Sandstone and Sandy Shale = 2.2

**Use this method only as a last resort**

**Use No. 4 sieve for penetration method only.**

For more information, refer to the manual of procedures for Earthwork.
Figure 7-3. Circular Slide Rule
Figure 7-4M. Plotted Ohio Typical Density Curves

* Computer re-drawn February 1996
Figure 7-4. Plotted Ohio Typical Density Curves

* Computer re-drawn February 1996
Figure 7-5M. C-88M Sand Cone Test With More Than 10% Passing 19mm Sieve
<table>
<thead>
<tr>
<th>Test of (check which):</th>
<th>□ Embankment</th>
<th>□ Subgrade</th>
<th>□ Base</th>
<th>□ Other</th>
<th>Min. Compaction Req.: 102 %</th>
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</thead>
<tbody>
<tr>
<td>From Sta 32 + 8' - 66 feet (or ft) of centerline, at approx. Elevaion 1000 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Read: "Manual of Procedures for Earthwork"

1. Weight of wet soil & (stone, if any) from auger hole + weight of container
   1. = 11.51 lb

2. Weight of container
   2. = 4.35 lb

3. Weight of wet soil & (stone, if any) from auger hole (#1 less #2)
   3. = 7.16 lb

4. Weight of 1/30 ft³ compacted wet soil + weight of container
   4. = 13.54 lb

5. Weight of 1/30 ft³ container
   5. = 9.91 lb

6. Weight of 1/30 ft³ compacted wet soil (#4 less #5)
   6. = 3.63 lb

7. Density of compacted wet soil (30 X #6)
   7. = 17.79 lb/ft³

8. **Average penetration reading (3 or more tests) using 1/ in³ needle
   8. = lb

9. **Average penetration resistance (#8 end area of needle)
   9. = lb/in²

10. Optimum moisture from Dry Weight Curve (Curve No. R)
    10. = 21.5 %

11. Moisture from Wet Weight Curve (Curve No. R) or by drying
    11. = 20.9 %

12. Amount above □ or below □ optimum moisture (difference #10 & #11)
    12. = 0.5 %

13. Weight of sand + weight of density-cone apparatus
    13. = 17.44 lb

14. Weight of density-cone apparatus
    14. = 17.44 lb

15. Weight of sand in density-cone apparatus (#13 less #14)
    15. = 12.81 lb

16. Volume of density-cone apparatus (recorded on density-cone)
    16. = 0.151 ft³

17. Density of sand (#15 #16)
    17. = 84.8 lb/ft³

18. Weight of density-cone and remaining sand after cone is filled on leveled area
    18. = 15.83 lb

19. Weight of sand required to fill cone on leveled area (#13 less #18)
    19. = 1.99 lb

20. Weight of density-cone and remaining sand after filling auger hole & cone
    20. = 3.58 lb

21. Weight of sand in auger hole and cone (#18 less #20)
    21. = 2.17 lb

22. Weight of sand in auger hole (#21 less #19)
    22. = 0.87 lb

23. Volume of auger hole (#22 #17)
    23. = 0.062 lb/ft³

Procedure when sample contains less than 1/10 total weight in stone retained on 3/4" or No. 4 sieve***

24. Density of wet soil in fill (#3: #23)
    24. = 114.4 lb/ft³

25. Density of dry soil in fill [(100 x #24) (100 + #11)]
    25. = 99.9 lb/ft³

26. Max dry density (From Curve No. R)
    26. = 99.9 lb/ft³

27. Compaction (#25 #26 x 100)
    27. =

Procedure when sample contains more than 1/10 total weight in stone retained on 3/4" or No. 4 sieve***

28. Weight of Sample (33)
    28. = 7.16 lb

29. Weight of stone removed from sample and retained on 3/4" or No. 4 sieve
    29. = 1.06 lb

30. Percent stone in sample (#29 + #28 x 100)
    30. = 14.8 % > 10%

31. Weight of stone in one cubic foot of material (#24 x #30 / 100)
    31. = 16.93 lb

32. Volume of stone in one cubic foot of material (#31 / (Sp. Gr.* 62.4))
    32. = 0.1044 ft³

33. Volume of wet soil in one cubic foot of material (1.00 less #32)
    33. = 0.8956 ft³

34. Weight of wet soil in one cubic foot of material (#24 less #31)
    34. = 91.5 lb

35. Density of wet soil (#34 #33)
    35. = 108.9 lb/ft³

36. Density of dry soil [(#35 x 100) (#11 + #100)]
    36. = 90 lb/ft³

37. Compaction with stone removed (#36 x #26 x 100)
    37. = 90.1 %

38. Moisture from zero air voids curve using (#25 or #36)
    38. = 31.5 %

*Average Specific Gravity Values: Limestone: 2.6; Gravel: 2.5; Sandstone and Sandy Shale: 2.2

**Use this method only as a last resort.

***Use No. 4 sieve for penetration method only.

Does material tested meet specification requirements for; (write yes or no on each of following)

Max. dry weight NO □ Moisture YES □ Compaction NO 102 % REQUIRED

Does test check zero air voids curve (check which): Yes □ No □

Action taken by (check which): □ Inspector □ Project Engineer

Material tested does not meet specification requirements:
□ Additional rolling ordered □ Aerating ordered □ Watering ordered □ Other

Computed By FLACKY JAKE Checked By RALPH LOUSE

Figure 7-5. C-88 Sand Cone With Test More Than 10% Passing 3/4" Sieve
Figure 7-6. Sand Cone Apparatus
For Soils of Specific Gravity (G) of 2.67

\[ W_{(\text{Max})} = \frac{1000}{D} - \frac{1}{G} \times 100 \]

Figure 7-7M. Zero Air Voids Curve
Figure 7-7. Zero Air Voids Curve

For Soils of Specific Gravity (G) of 2.67

\[
W_{(\text{Max})} = \frac{62.4}{D} - \frac{1}{G} \times 100
\]

Dry Weight (D) lbs. per cu. ft. (Steps 25 or 36 of C-88)

Moisture (W Max.) Percent

Dry Weight (D) lbs. per cu. ft. (Steps 25 or 36 of C-88)
## Chapter 8.0 Compaction Testing of Soil Using the Cylinder Density Test

<table>
<thead>
<tr>
<th>Section/Figure</th>
<th>Page</th>
<th>Old Section</th>
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<tbody>
<tr>
<td>8.1 Description</td>
<td>8-2</td>
<td>23.4.4.1</td>
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<tr>
<td>8.2 Conditions of Use</td>
<td>8-2</td>
<td>23.4.4.2</td>
</tr>
<tr>
<td>8.3 Equipment</td>
<td>8-2</td>
<td>23.4.4.3</td>
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<td>23.4.4.4</td>
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<td>8.5 Determining Percent Compaction Procedure</td>
<td>8-5</td>
<td>23.4.4.5</td>
</tr>
<tr>
<td>8.6 Procedure for Multiple Density Tests</td>
<td>8-5</td>
<td>23.4.4.7</td>
</tr>
</tbody>
</table>

- Figure 8-1 Cylinder Density Apparatus | 8-6  | 23-7        |
- Figure 8-2M Example of C-89M Compaction Test Using the Cylinder Density Method | 8-7  | 23-8        |
- Figure 8-2 Example of C-89 Compaction Test Using the Cylinder Density Method | 8-8  | 23-8        |
8.0 Compaction Testing of Soil Using the Cylinder Density Test

8.1 Description

The soil cylinder density apparatus and procedure is used for field density determinations in fine grain soil such as clay or silt. This method consists of driving a cylinder of known volume into the compacted soil, determining the weight of the soil contained in the cylinder, and computing the wet weight density of the soil in place.

THIS METHOD IS NOT RECOMMENDED AND SHOULD ONLY BE USED AS A LAST RESORT.

8.2 Conditions of Use

The cylinder density method is an alternate to the sand-cone method for determining density for compaction control of soil embankments and subgrades. The cylinder density method is used only for fine grained soils such as clay or silt. This method cannot be used with accuracy for granular material or for soils that contain a considerable quantity of stone or gravel.

The cylinder density test can be made more quickly than the sand-cone test, and its use is recommended for that reason where conditions are favorable. It is especially recommended for large areas of uniform, fine grained soil.

It is not intended that the cylinder density method replace the sand-cone method for fine grained soils. Where the field density as determined by the cylinder method compares favorably with that determined from check test by the sand-cone method, the cylinder method is considered satisfactory. In any situation where soil conditions are such that the accuracy of the cylinder tests is questionable, use the sand-cone or nuclear methods.

8.3 Equipment

1. Cylinder density apparatus, Figure 8.1, including the following:
   - Several soil density cylinders, 47mm (1.850 inch) diameter by 72mm (2.834-inch) deep
   - Adapter that connects cylinder to handle
   - Pipe handle
   - Rammer, sleeve type
   - Steel push-out rod, 12mm (1/2-inch) diameter by 117mm (46 inches)
2. Balance, capacity 610 grams, sensitive to 0.1 gram, with case
3. Knife
4. Wood chisel
5. Oil can and lubricating oil
6. Hand shovel
7. Wire brush
8. Wiping rags
9. Embankment compaction control kit. (See Section 4.4)
10. Typical curve slide rule, set of typical moisture-density curves, or moisture density curve representative of soil being tested.
8.4 Determining Wet Density

Use Form C-89M (C-89), Figure for recording test results, and proceed as follows:

1. Weight the cylinder and record the weight in grams. For accurate results protect the scales from wind or drafts during weighing. The carrying case is provided with a vision door so that it may be used for protection against wind. Place scales in the case while making weighings and check for balance by observing the scales through the closed vision door.

2. Apply a thin coating of lubricating oil to the cylinder, inside and outside.

3. Assemble handle, adapter, and cylinder, taking care that the threads are free from dirt and that the cylinder is screwed into the adapter with a loose fit of the threads. If the fit of the threads is tight, it will be difficult to remove the cylinder from the adapter after driving.

4. At the location where the cylinder density test is to be made, prepare an area slightly larger than the area of the cylinder by removing any loose material that may exist on the surface, using a hand shovel or other suitable means, and level the resulting surface.

5. Place the handle through the hole in the rammer and place the assembled apparatus in a vertical position over the prepared area.

6. Grasp the upper end of the handle with one hand to hold it in a vertical position, and with the other hand grasp the rammer firmly and drive the rammer against the adapter, retaining a firm grip on the rammer throughout the blow. By successive blows of the rammer on the adapter, drive the cylinder into the soil in the prepared area. Cease driving when approximately one-third of the adapter has been driven below the surface.

7. Extract the cylinder and adapter from the resulting embedded position in the soil in the following manner so that the lower end of the cylinder will remain filled with soil:
   A. Rotate the handle of the apparatus slowly in several circles of gradually increasing diameter about the axis of the original vertical position of the handle, and then slowly lift the apparatus vertically.
   B. In wet plastic soil, force the wood chisel or a similar tool into the soil next to the adapter and cylinder to the depth of the bottom of the cylinder prior to lifting the apparatus, to prevent suction from disturbing the soil in the cylinder when the apparatus is being lifted.

8. Unscrew the cylinder with contained soil from the adapter and examine it. For accurate density results the soil should extend above the top of the cylinder, and should be about even with the bottom of the cylinder, or extend beyond it. If the contained soil has broken back into the cylinder by more than 9.53mm (3/8 inch) at the bottom of the cylinder, discard the soil and secure another sample by driving the cylinder again in the manner described above.

9. After examination has established that the soil fills the cylinder within the tolerance of not more than 9.53mm (3/8 inch) at one end, trim away the soil which extends beyond the top (threaded end) of the cylinder with a knife, leaving the soil approximately even with the top of the cylinder in a vertical position on a level surface, with the threaded end down. Using the knife and wood chisel, carefully level the soil even with the end of the cylinder at the cutting end by trimming away soil which projects, and filling depressions. Invert the cylinder, and with a cutting end resting on the
level surface, carefully level the soil even with the threaded end of the cylinder. Wipe from the outside of the cylinder any soil that adheres to it.

10. Weigh the cylinder and contained soil, and record the weight in grams. From this weight subtract the weight of the cylinder in grams, obtaining the weight of the contained soil in grams. Multiply (Divide) this weight of contained soil in grams by 8.009 (2) on the C-88M (C-88), computing the result to one decimal place. This result is the wet weight density of the soil in kg/m³ (pounds per cubic foot). The cylinder has been made to a volume so that by dividing the weight of the contained soil by 2, the result will be the weight per cubic foot of the soil (for C-88 Form). Notice on the metric form (C-88M) the numbers are multiplied by 8.009 while on the English form, C-88, the numbers are divided by 2.

11. Remove the soil from the cylinder in the following manner:
   A. Screw the cylinder and contained soil into the adapter.
   B. Insert the push-out rod into the handle, so that one end of the rod extends through the adapter and rests on the soil at the threaded end of the cylinder.
   C. Place the other end of the push-out rod on the ground, and with the assembled apparatus in a vertical position, push down on the handle, thus forcing the soil from the cylinder with the push-out rod.

12. Examine the soil thus removed from the cylinder to determine if it is uniform and free from stones, breaking the soil into small pieces during the examination. If the soil from the cylinder is uniform and consists predominantly of fine grained soil, the density results obtained may be considered representative of the soil being tested. If the soil from the cylinder should contain a large stone or a nonuniform aggregation of small stones, the sample may not be representative. In such instance the density results should be discarded, and another sample secured.
8.5 Determining Percent Compaction

Having secured the wet weight density in pounds per cubic foot by the cylinder density method, procedure is as follows to determine the percent compaction:

1. Secure a sample of soil of approximately 3 kilograms (six pounds) immediately adjacent to the location where the cylinder density test was made.
2. Using the soil sample and the embankment control kit and typical curves, determine the percent compaction as described in Sections 7.5 and 7.6.

Determine the percent of compaction as follows:

1. Pass the soil sample through the 4.75mm (No. 4) sieve.
2. Compact the sample in the 0.000943m³ (1/30-cubic foot) mold in the manner described in Sections 7.2 and 7.3, and determine the compacted wet weight and penetration resistance.
3. You may use drying method to determine the moisture content. Penetration resistance should be used as a last resort.
4. Select the moisture-density curve that represents the material.
5. From the moisture-density curve selected, note and record the actual moisture, optimum moisture, and maximum dry weight.
6. Calculate weight of dry soil in one cubic meter (one cubic foot) of fill.
7. Calculate percent compaction.

See example on Figure 8-2M (8-2) shows an example of test results recorded on Form C-89 M (C-89).

8.6 Procedure for Multiple Density Tests

Where the Contractor’s operations for construction of embankment will permit, considerable time can be saved if several soil samples taken from a large area are collected and tested at the same time, rather than making a complete test as each sample is taken. Also, this practice permits the Inspector to make immediate comparisons of soil sample and test results so that if one varies appreciably from the others the matter can receive his attention at once. To take advantage of this method, procedure is as follows:

1. Set up balances for weighing near the large area from which soil is to be tested.
2. Weight three or more cylinders separately, identify each cylinder, and record the weight of each cylinder under the proper test number on Form C-89 M (C-89), Figure 8-2M (8-2).
3. In succession, drive the cylinders into the soil at the locations to be tested, noting the location of each sample on Form C-89 M (C-89).
4. Return the cylinders filled with soil to the location of the balance and trim the soil level with the ends of the cylinders.
5. Weigh all cylinders.
6. Calculate the density.
7. Record all pertinent information on Form C-89 M (C-89), Figure 8-2M (8-2).
Figure 8-1. Cylinder Density Apparatus
Figure 8-2M. Example of C-89M Compaction

Test Using the Cylinder Density Method
### Figure 8-2. Example of C-89 Compaction

#### Test Using the Cylinder Density Method

<table>
<thead>
<tr>
<th>Test No. 1 Procedure for Determining Wet Weight Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Weight of cylinder and contained wet soil</td>
</tr>
<tr>
<td>b. Weight of cylinder</td>
</tr>
<tr>
<td>c. Weight of contained wet soil (a less b)</td>
</tr>
<tr>
<td>d. Density of wet soil in fill (c + 2)</td>
</tr>
</tbody>
</table>

**Note:** Numbers of the following steps are the same as corresponding steps on Form C-88 (Water Added)

4. Weight of 1/30 ft³ compacted wet soil + weight of container
5. Weight of 1/30 ft³ container
6. Weight of 1/30 ft³ compacted wet soil (#4 less #5)
7. Density of compacted wet soil (30 x #6)

| 8. ***Average penetration reading (3 or more tests) using 1/100 in² needle |
| 9. ***Average penetration resistance (#8 end area of needle) |
| 10. Optimum moisture from Dry Density Curve (Curve No. M)        |
| 11. Moisture from Wet Density Curve (Curve No. M) or by drying    |
| 12. Amount above or below optimum moisture (difference #10 and #11) |

25. Density of dry soil in fill [[100 x d + (100 + #11)] / 100]
26. Max. Density (From Curve No. M)
27. Compaction (#25 + #26 x 100)

Use following spaces to record data for additional tests in nearby areas where soil and moisture conditions are the same by inspection, omitting Steps 4 through 12. If soil or moisture conditions are not the same for the other areas to be tested, use a new Form C-89 instead of the following spaces.

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<tr>
<td>d. * Wt Density of soil (c + 2) (lb/ft³)</td>
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<td>127.4</td>
<td>130.1</td>
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</tr>
<tr>
<td>25. * [(100 x d) + (100 + #11)] (lb/ft³)</td>
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* Refers to corresponding steps for Test No. 1 above
** Use value for moisture and max. dry wt. per cubic foot obtained in Test No. 1
*** Use this method only as a last resort

Does material tested meet specification requirements for: (write yes or no on each of the following)

Max. dry density **YES**; Moisture **YES**; Compaction **YES**

Does test check zero air voids curve (check which); **Yes** ☑ **No** ☑

Action taken by (check which); ☑ Inspector ☑ Project Engineer

If material tested does not meet specification requirements:

☑ Additional rolling ordered ☑ Aerial seeding ordered ☑ Watering ordered ☑ Other

Computed By: **JACK JAGGER**

---

STATE OF OHIO DEPARTMENT OF TRANSPORTATION
### INDEX

**Chapter 9.0 Compaction Testing for Granular Materials**

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9.0 Compaction Testing for Granular Materials

9.1 General Explanation

The purpose of this section is to give general instructions for the determination of the field density of granular materials used as bases, subbases and embankment materials. Granular soils are soils defined as granular as per 203. The dry weight of the material is used for compaction control, in accordance with the instructions in this section. The wet weight method is no longer used.

For granular material in embankment, 203.09(b) of the specifications requires compaction to the density established as satisfactory to the Engineer based on field density test. The Engineer may establish the required density by using the one point proctor with the Ohio Typical Density curves used for soils, making a moisture-density curve or by test section method. For base and subbase materials, the test section method must be used. In Sections 310.03 and 304.04 of the specifications, subbase and aggregate base materials are required to be compacted to at least 98 percent of the density of the established test section density.

Moisture-Density proctor curves and controls were originally developed to be used on cohesive (clays and silts) soils. Errors or complications arise when trying to extrapolate these principles to granular materials.

This is the reason why the Engineer or Inspector is given the latitude to choose the density requirements that are based on the field density tests.

A one point proctor method using the typical density curves may be used for granular soils. The top curves of the Ohio Typical Curves A through E are usually chosen in this case. But often the moisture is incorrect. These curves will only work in a small amount of cases. This method should only be used as a last resort.

In general, if a material is classified as granular, or is a base or subbase material, a granular moisture-density curve needs to be made a few weeks before the Contractor proposes to use the material. This may be done in the field or by the Laboratory. The maximum density and optimum moisture data obtained from this curve may or may not work in the field. The following are examples and further explanation of some of the problems associated with the density control of these granular materials.

Examples of Density Problems

Example 1: When the Contractor Uses a Sandy Material.

It may not be possible to obtain the maximum density of the curve no matter how or with what equipment the Contractor uses to compact the material. This is particularly true for sandy material with silt fines.

Reason: The proctor mold used to produce the moisture-density curve confines the sand in all directions. In the field, since sand doesn’t interlock or knit together well without being confined, the roller will squeeze the material laterally and proctor
densities may not be obtained. The sand may not even support the weight of the roller. The Lab and field confining pressures and compactive effort are not compatible in this case.

Solution: The density obtained by using the test section method should be used for density control.

Example 2: When the Contractor Uses a Granular Material like 304 or a Coarse Grained Aggregate.

In this case the maximum dry densities obtained in the field, using the test section method often exceed the maximum dry density on the moisture-density curve.

Reason: The 304 type material is well interlocked and allows the roller to transfer more energy, comparative effort or load to the material. This roller load or energy is much larger than the proctor hammer load of 2.5 kilograms (5.5 pounds) dropped 305mm (12 inches) in three lifts.

Solution: Use the test section maximum density.

Moisture Problem

The granular material should be brought on site at or near optimum moisture. When this is not the case the moisture should be added before a significant amount of rolling occurs. This is particularly important for 304 gradation materials since water cannot be readily absorbed by this material.

Optimum moisture from the proctor moisture-density curve of granular materials is not always correct.

Sometimes the granular material begins to roll or pump when compacting the material at or near optimum moisture obtained from the moisture density curve. This may be caused by excess water in the material. In this case, dry the granular material until stability is achieved. Usually 1-3 percent will work. A granular moisture density curve should always be used to estimate the maximum density and optimum moisture.

Summary

When using granular material or granular subbase or base materials the proctor moisture density curve is used as a guide. The exact maximum density and optimum density can only be found in the field.

The test section method has been used for many years and should be used to find the maximum density in the field. Adjustment to the optimum moisture may also be required.

9.2 Equipment for Compaction Testing

1. Embankment compaction control kit. (See Section 4.4.)
2. Sand-cone apparatus or Troxler 3440 nuclear gauge.
3. 11 to 23 kg (25 to 50 pounds) dry sand.
4. Gasoline stove or other drying equipment.
5. Large screwdriver or similar instrument.
6. Baking pans approximately 300 x 200 x 63mm (12 x 8-1/2 x 2-1/2 inches).
7. Large Spoon.
8. Sieve with 19mm (3/4-inch) square opening.
9. 50mm (2-inch) paint brush.
10. Form C-90M (C-90) or C-135M (C-135B).
9.3 Granular Moisture Density Curve Determination

Purpose
The purpose of this section is to outline procedures and give directions for determining optimum moisture and maximum dry weight for granular materials. This information is needed for field density control of granular materials placed in embankment, subgrade, base, subbase and other miscellaneous uses. The equipment required is the same as listed in Section 9-2.

Procedure
Use Form C-90M (C-90), Lines 1 through 10 to record test data as obtained by the procedure outlined in this section. Figure 9-1 shows curves plotted from the test data from Figure 9-2M (9-2). Basically it is the same procedure outlined in Section 4.4 with a few modifications.

1. Obtain a representative sample of the material, approximately 18 kg (40 pounds).
2. Pass the material through a 19mm (3/4-inch) sieve.
3. Divide the portion passing the 19mm (3/4-inch) sieve into six equal parts.
4. Wet or dry one portion of the sample as required to bring the moisture content from 4 to 6 percent below optimum.
5. Weigh the container. Record on Line 2 of Form C-90M (C-90).
6. Take a proctor test. (See Sections 7.2 and 4.4 and Figure 4.6.) Form a specimen by compacting the prepared soil in the 102mm (4-inch) diameter mold, volume 0.000943m³ (1/30 cubic foot), included in the compaction control kit, in three equal layers to give a total compacted depth of about 127mm (5 inches). Compact each layer by applying 25 uniformly well distributed blows from the 12 kg (5-1/2 pound) rammer dropping from a height of 305mm (12 inches) above the elevation of the soil. Insure that the cylinder is resting on a uniformly rigid foundation during compaction. A concrete block is usually used.
7. Remove the collar from the mold and strike off the material on the cylinder with a straightedge. If holes develop by the removal of the coarse material, fill these with fines from the sample.
8. Record weight of the compacted material and the container on Line 1 of Form C-90M (C-90).
10. Multiply Line 3 by 1060 (30) and record on Line 7. This is the wet density of the material.
11. Remove the material from the mold and dry by any appropriate method outlined in Chapter 3.
12. Weight the dried material and record on Line 4 of Form C-90M (C-90).
13. Determine the percent moisture of the sample following directions given on Lines 5 and 6 of Form C-90M (C-90).
14. Determine the dry weight per cubic meter (per cubic foot) of compacted dry material following procedure outlined on Lines 7 and 8 of Form C-90M (C-90).
15. Add water in sufficient amount to increase the moisture content by 1 or 2 percent to the second portion and repeat the procedure outlined in (5) through (14).
16. Repeat step (15), each time adding water, until at least four readings for wet weight, dry weight and moisture content are obtained, and until there is a decrease in the wet weight. Two points should be obtained on each side of optimum moisture.
17. Use Figure 9-1 as an example, and plot test data as follows:
   A. Plot wet weight versus moisture content of the successive tests on linear graph paper.
Draw a smooth curve between the successive points. The peak of this curve is the maximum wet weight for the material being tested. The maximum wet weight is not used for compaction acceptance.

B. Plot dry weight versus moisture content of the successive tests on linear graph paper.

Draw a smooth curve between the successive points. The peak of this curve is the maximum dry weight of the granular material and is used for compaction acceptance. The moisture content at this point is the optimum moisture.
9.4 Density Determination of Granular Material Using a Troxlor 3440 Nuclear Gauge

The procedure for testing granular materials on Form C-135 B-M (C-135B) are similar to those detailed in Chapter 6 for soils. The deviations are noted below and in most cases the procedure is listed in outline line form. For further details see Chapter 6 or the owner’s manual.

1. Perform the standard count. Record this information on lines 4 and 7 of the C-135 B-M (C-135B).
2. Select a location for the granular density test which is representative of the rolled area of the granular material being placed. Level the density test location carefully.
3. Prepare the location for the scraper plate or nuclear gauge. Fill the voids with fine native material if required. Excessive voids will produce erratic numbers and should be avoided.
4. If the type of granular material allows it, the probe may be used to take the readings. If the material is too coarse, voids may form when you drive the drill rod and the hole may collapse if the material is too fine. It is not required to use the probe and in most cases the back scatter mode should be used. If sandy material is being tested, the material may be loose on the surface. Testing in the deepest direct position may be the only way to obtain accurate results.
5. Take a backscatter reading at the prepared location.
6. Drive the drill rod with the scrapper plate and mark the location if a direct transmission reading is going to be taken.
7. Take a reading in the direct position at the lift thickness of the material. The probe should not extend deeper than the lift thickness.
8. Compare the backscatter reading to the direct position reading. They should compare within a kilogram (pound) or so. If they do not, the likely problem would be non-uniform water content or non-uniform density.
9. Record the densities and the moisture on Lines 5, 6, and 8 on Form C-135B-M (C-135B). See example 9-3M(9-3).
10. Compare these readings to the maximum density and optimum moisture obtained on the moisture density curve (Figure 9-1) made from Lines 1 through 10 on Form C-90M (C-90) or the maximum density found by the test section method. See Figure 9-2M (9-2).
11. The used maximum dry density and optimum moisture may be recorded on Lines 14 and 15 and on the top of the Form C-90M (C-90). Note where this information came from. See Figure 9-2M (9-2) Lines 11 and 12.
12. Note that the optimum moisture stated on Line 14 of the Form C-135M (C-135B) in Figure 9-3M (9-3) is different than found by the moisture-density curve on figure 9-1M (9-1). In this case the moisture needed reduced to secure the stability. See the explanation at the beginning of this chapter.
13. Find the percent compaction on Line 17 of the C-135M (C-135B). If the compaction is greater than 98 percent the material passed.
9.5 Density Determination of Granular Material Using the Sand-Cone on Form C-90M (C-90)

The below procedure is approximately the same as detailed in Chapter 7.

1. Select a location for the granular density test that is representative of the rolled area of the granular material being placed. Level the density test location carefully. Record the weight.

2. Record the weight of the sand cone apparatus on line 14.

3. Fill the sand-cone apparatus with dry uniform sand as follows:
   A. With the valve closed, pour sand into the upper cone until it is full.
   B. Open the valve allowing the jar and lower cone to fill and at the same time keep the upper cone filled with sand.
   C. After the jar and lower cone are filled, close the valve and remove sand in the upper cone.
   D. Weight the density-cone apparatus filled with sand and record the weight on line 14.

4. Determine the density of the sand by following lines 15 through 17.

5. Invert and firmly seat the density-cone apparatus on the leveled area. Mark the surface of the granular material by scribing around the edge of the seated apparatus with a pencil or other pointed tool or instrument. This marking will permit the seating of the density-cone in the identical position during performance of other tests. Thin plastic, which will conform to surface irregularities, may be used on the surface under the sand-cone apparatus to facilitate the later removal of the sand.

6. Open the valve permitting sand to flow until the upper cone is filled. Close the valve and remove the density-cone apparatus from the test area. Weigh the apparatus and remaining sand and record the weight on Line 18, Form C-90M (C-90). Brush the sand from the test area taking care not to disturb the surface or marking of the test area, or if plastic is used, lift the plastic and discard the sand.

7. Dig a hole in approximate center of the test area and save all material removed. To dig the hole use a large screwdriver or similar tool or instrument in such a manner as to gently loosen the surface. A baking pan with a hole should be used to prevent the loss of material during this step. Start with a small area, increasing the area to a diameter of about 127mm (5 inches) as the hole reaches full depth of the compacted course. Take care in loosening and removing the granular material so not to disturb the material in place which forms the sides and bottom of the hole. In all cases where the depth of-layer and type of material will permit, the hole shall be large enough to secure a volume not less than that shown in Table 1. Where the layer is so thin that the designated volume cannot be obtained, secure the largest hole possible. Where the volume of the largest hole possible is less than designated in Table 1, note on the compaction report the reason for using the smaller volume.
### Table 1

<table>
<thead>
<tr>
<th>Maximum Size Particle</th>
<th>Minimum Test Hole</th>
<th>Minimum Weight Moisture Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>m³</td>
<td>cu. ft.</td>
</tr>
<tr>
<td>50.0</td>
<td>0.002</td>
<td>0.070</td>
</tr>
<tr>
<td>25.0</td>
<td>0.0017</td>
<td>0.060</td>
</tr>
<tr>
<td>12.5</td>
<td>0.0014</td>
<td>0.050</td>
</tr>
<tr>
<td>4.75</td>
<td>0.0007</td>
<td>0.025</td>
</tr>
</tbody>
</table>

6. Use the brush to remove any loose material adhering to the sides and bottom of the finished hole. Transfer granular material removed from the hole to a container so as not to lose any material. Keep container covered so no appreciable loss of moisture will occur. Weigh and record the weight of the wet granular material taken from the hole on lines 24 through 26.

7. Select a representative sample of the wet granular material from the material removed from the test hole for a moisture determination. The minimum weight of sample for moisture determination is as given in Table 1. Dry the sample by any appropriate method outlined in Chapter 3.

8. Determine the volume of the test hole in the following manner:
   A. Seat the upper cone over the test hole in the same position as originally occupied on the test area.

B. Open the valve, allowing sand to fill the test hole and upper cone.

C. Close the value and remove the density-cone apparatus from the test area. Weigh the apparatus and remaining sand and record weight on Line 20, Form C-90M (C-90).

9. Calculate moisture content and dry in-place density as indicated on Figure 9-2M (9-2). The procedures for determining optimum moisture, maximum dry weight and in-place density are shown on Form C-90M (C-90) and are self-explanatory. Further details are detailed earlier in this chapter.

10. Compare the dry in-place density with 98 percent of the dry test section density or 98 percent of the moisture density curve. Compaction is satisfactory if the dry in-place density is equal to or greater than 98 percent of the dry test section density or the moisture density curve. See Section 9.1 for further explanation.
9.6 Compaction Control Using a Test Section for Granular Material, Subbase or Aggregate Bases

Purpose

The purpose of this section is to outline procedures for the compaction control of granular material, base and subbase materials, and procedures for building a test section according to 310.03 or 304.04. Section 310.03 states:

“At the beginning of the work the Contractor shall build a test section for the purpose of the Engineer determining density requirements for the material to be placed. With the moisture content of the material near optimum, the compaction of the test section shall be continued with approved compaction equipment, consisting of rollers alone or vibratory equipment and rollers, until there is no appreciable increase in density as determined by test. Approve compaction equipment shall consist of rollers alone, vibratory equipment alone only where subbase material is of such a nature that it will not support rollers. For the remainder of the work the subbase course shall be compacted until the density is at least 98 percent of the weight in the test section. During the construction of the project, if there is an appreciable change in grading of the material or a change of source of material, a new test section shall be built in order to establish a new weight for the density requirement.

Compaction of the subbase course shall immediately follow the spreading operation."

Similar requirements are stated in 304.04. Before the work begins a moisture-density curve should be made to approximate the optimum moisture and maximum density.

Procedure for Constructing a Test Section

1. Designate a test section of sufficient size to permit the operation of compacting equipment in a normal manner.

2. Spread the material with approved spreaders, in layers not over 150mm (6 inches) compacted depth, except for variable thickness subbase under pavement and shoulders adjacent to the pavement, the material may be spread in layers of not more than 200mm (8 inches) compacted.

3. Insure that the moisture content of the material is not less than optimum minus 2 percent and not more than optimum plus 1 percent. Watering, drying or manipulating may be necessary to secure uniform distribution of water throughout the material. See explanation on the reduction of moisture at beginning of this chapter.

4. Compact the material using approved compaction equipment, consisting of rollers alone, or vibratory equipment and rollers. Vibratory equipment alone may be used only where subbase material is of such a nature that it will not support rollers. Keep an accurate record of the number of coverages on C-90M (C-90).

5. Make a density test in the compacted test section as described in Section 9.3 or 9.4 after the initial seating of the material.

6. Further compact the test section with two additional coverages of any approved type of vibratory device or roller.

7. Make a secondary density test in the compacted test section near the location of the first test. If the two tests vary by not more than 32 kg/m³ (2 pounds per cubic foot), the higher of the two tests will be considered satisfactory test section density.
8. If the density after additional rolling has increased more than 2 pounds per cubic foot, apply two more compaction coverages and make an additional density test. Repeat this process of compacting and testing until the density increase is less than 2 pounds per cubic foot with two increased compaction coverages. The resulting highest density will be considered satisfactory test section density.

9. Determine and record on Form C-90M (C-90) or C-135B-M (C-135B) the wet density, dry density and moisture content. For the remainder of the work, the material shall be compacted to at least 98 percent of the dry weight of the test section.

When to Apply Water
Moisture specifications require that when so ordered by the Engineer, water will be applied to aid in the compaction. Moisture content at the time of compaction should be at or near optimum. In general, if the moisture is more than 2 percent drier than optimum at the time of compaction, the Engineer should require that water be applied. Where the subbase material has unusually high permeability such that added water readily penetrates the subbase and may soften the subgrade, it is permissible to compact the subbase at a moisture drier than 2 percent below optimum, providing satisfactory density and stability can be obtained. If the moisture is greater than optimum and the material displaces or deflects under the compacting equipment or does not compact properly due to excess moisture, the Engineer should require that the material be allowed to dry before compacting. The same problem can exist for moisture contents at optimum. See explanation earlier in this chapter.

Checks of Depth and Width
At the beginning of the spreading operation, the Contractor must adjust the spreader to produce sufficient loose depth for compaction to at least plan thickness, as determined by measurements after compaction. Make occasional checks during the spreading and compacting operations to insure that adequate uniform depth after compaction is being obtained. The purpose of these checks is to control the spread only, and they need not be recorded.

After fine grading the subbase, make checks for depth at intervals of approximately 150m (500 feet). The interval between checks may be extended to 300m (1,000 feet) where the depth is consistently uniform and at least equal to plan depth.

Variations in depth from plan thickness are to be expected. A tolerance of 19mm (3/4 inch) can be allowed on individual depth measurements. Where measurements show the thickness to be consistently less than plan requirements, by any amount, it is considered

Reports and Frequency of Tests
Use Form C-90M (C-90) or C-135B-M (C-135) for recording and reporting results of compaction tests.

Submit promptly the original to the District office and retain one copy for the project files.

Under normal field conditions, the number of density and moisture checks required should not be great after the initial period of adjustment, assuming that the work is proceeding smoothly and materials being compacted are uniform. The Engineer may learn quickly to judge the moisture content of the material by appearance and feel. If adequate densities are being obtained and the proper moisture content is being maintained, the job of inspection may then be principally one of deciding on the number of coverages of the roller required for satisfactory test section density and seeing that this number of coverages actually is made. Under such conditions only one or two density checks per day may be required. Where conditions are more variable, density and moisture checks may be needed as often as once an hour. The exact number of checks needed can be determined by the Engineer.
that plan requirements have not been met, and corrective action is required. Where an individual measurement is less than plan requirements by 19mm (3/4 inch) or more, an additional measurement shall be made not more than 30m (100 feet) away. If the depth at this location is plan thickness or greater, consider the area being checked satisfactory. If the depth at this location is less than plan thickness, make sufficient depth checks at additional locations to define the deficient area, and require correction.

Record on an appropriate form all depth measurements and the station locations at which they were made, and place in the project records.

Measurements to document the width of subbase need not be made prior to placement of overlying courses because the width of subbase can readily be verified visually after succeeding courses are placed. After the overlying pavement is placed, make a visual verification that the width of the subbase conforms to or exceeds the plan width, and file a statement to this effect in the project records.
Figure 9-1M. Moisture Density Curve for Granular Material
Figure 9-1. Moisture Density Curve for Granular Material
**PROCEDE FOR DETERMINING OPTIMUM MOISTURE AND MAXIMUM DRY WEIGHT**

<table>
<thead>
<tr>
<th>Determination No.</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of 0.000943 m³ compacted wet material and container</td>
<td>4.091</td>
<td>4.191</td>
<td>4.255</td>
<td>4.191</td>
<td>kg</td>
</tr>
<tr>
<td>Weight of 0.000943 m³ container</td>
<td>1.977</td>
<td>1.973</td>
<td>1.973</td>
<td>1.973</td>
<td>kg</td>
</tr>
<tr>
<td>Weight of 0.000943 m³ compacted wet material (#1 less #2)</td>
<td>2.118</td>
<td>2.218</td>
<td>2.282</td>
<td>2.218</td>
<td>kg</td>
</tr>
<tr>
<td>Weight of 0.000943 m³ compacted dry material (by drying)</td>
<td>2.046</td>
<td>2.096</td>
<td>2.100</td>
<td>2.000</td>
<td>kg</td>
</tr>
<tr>
<td>Weight of water (#3 less #4)</td>
<td>0.072</td>
<td>0.122</td>
<td>0.182</td>
<td>0.218</td>
<td>kg</td>
</tr>
<tr>
<td>Moisture in percent (#5 + #4 x 100)</td>
<td>3.5</td>
<td>5.8</td>
<td>8.7</td>
<td>1.9</td>
<td>%</td>
</tr>
<tr>
<td>Density of compacted wet material (1060 x #3)</td>
<td>2245</td>
<td>2635</td>
<td>2149</td>
<td>2351</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Density of compacted dry material (100 x #7) + (100 + #6)</td>
<td>2.169</td>
<td>2.222</td>
<td>2.225</td>
<td>2.210</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Optimum Moisture from Field Density Curve</td>
<td>9. =</td>
<td>7.2</td>
<td>%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Dry Density from Field Density Curve</td>
<td>10. =</td>
<td>2.221</td>
<td>kg/m³</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TEST SECTION DATA**

| 11. Test Section compacted maximum dry density | 2.114 | kg/m³ |
| 12. Test Section compacted maximum wet density | 2.262 | kg/m³ |

**IN PLACE FIELD DENSITY DATA**

| 13. Weight of sand + weight of density-cone apparatus | 8.473 | kg |
| 14. Weight of density-cone apparatus | 2.540 | kg |
| 15. Weight of sand in density-cone apparatus (#13 less #14) | 5.933 | kg |
| 16. Volume of density-cone apparatus (recorded on density-cone) | 0.00419 | m³ |
| 17. Density of sand (#15 + #16) | 1.416 | kg/m³ |
| 18. Weight of density-cone and remaining sand after cone is filled on leveled area | 7.285 | kg |
| 19. Weight of sand required to fill cone on leveled area (#13 less #18) | 1.183 | kg |
| 20. Weight of density-cone and remaining sand after filling auger hole and cone | 4.037 | kg |
| 21. Weight of sand in auger hole and cone (#16 less #20) | 3.248 | kg |
| 22. Weight of sand in auger hole (#21 less #19) | 2.660 | kg |
| 23. Volume of auger hole (#22 ÷ #17) | 0.00145 | m³ |
| 24. Weight of wet material from auger hole + weight of container | 8.079 | kg |
| 25. Weight of container | 4.604 | kg |
| 26. Weight of wet material from auger hole (#24 less #25) | 3.475 | kg |
| 27. Weight of wet material taken for moisture sample | 0.907 | kg |
| 28. Weight of dry material taken for moisture sample (after drying) | 0.848 | kg |
| 29. Weight of water (#27 less #28) | 0.059 | kg |
| 30. Moisture in percent (#29 + #28 x 100) | 1.0 | % |
| 31. Density wet material in place (#26 ÷ #23) | 3.07 | kg/m³ |
| 32. Density dry material in place ([100 x #31] + (100 x #30)) | 2.740 | kg/m³ |
| 33. 98% of Test Section Compacted Maximum Dry Density (98% x #11) | 2.072 | kg/m³ |
| 34. 98% of Test Section Compacted Maximum Wet Density (98% x #12) | 2.072 | kg/m³ |

**NOTE:** Complete line 9 and 10 for all tests

Action taken by (check which):  ✔ Inspector  ✔ Project Engineer

If material tested does not meet density requirements:
- Additional rolling ordered  ✔ Aerating ordered  Watering ordered  ✔ Other

Computed By: BOB  DOG  Checked By: JANE CAT

D.O.T.: 1638

---

**Figure 9-2M. Example of C-90M Density Determination Using The Sand Cone Method**
Figure 9-2. Example of C-90 Density Determination Using The Sand Cone Method
Figure 9-3M. Example of C-135B-M Form

Nuclear Gauge Compaction

Chapter 9.0 Compaction Testing For Granular Materials

<table>
<thead>
<tr>
<th>Sample ID: 2223456-01</th>
<th>Personnel ID: 111-232-74</th>
<th>Date Sampled: 6/16/91</th>
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<tr>
<td>Type of Inspection: COMPACTION</td>
<td>Producer Code:</td>
<td>Contractor: RAT CONSTRUCTION</td>
</tr>
<tr>
<td>Material Code:</td>
<td>Test Results: PASSED</td>
<td></td>
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<table>
<thead>
<tr>
<th>Project/P.O.</th>
<th>P.O. Ind.</th>
<th>Item Code</th>
<th>Ref. Number</th>
<th>Item Code</th>
<th>Ref. Number</th>
</tr>
</thead>
<tbody>
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<td>883-90</td>
<td>310</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test of (check which): □ Embankment □ Subgrade □ Base □ Other □ Min. Compaction Req.: %
Test of (check which): □ Limestone □ Gravel □ Slag □ Sandstone □ Granulated Slag □ Other
From Sta. +000 at meters 10 (ft) or ft. of centerline to Sta. +000 at 5 meters (ft) or ft. of centerline, at approx. Elevation m
See Report No. (check which): Wet □ Dry □ Maximum Density from Test Section kg/m³ Optimum Moisture %
98% of Max. Density kg/m³ Check Method used: □ Direct Transmission □ Backscatter Probe Depth mm

1. Station of test
2. Distance right or left of centerline if different than above (m)
3. Approximate Elevation if different than above (m)

### Procedure for Determining Dry and Wet Density

4. Standard Count for Density
5. Wet Density of soil from gauge (kg/m³)
6. Dry Density of soil from gauge (kg/m³)

<table>
<thead>
<tr>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1522</td>
<td>2246</td>
<td>2139</td>
</tr>
</tbody>
</table>

### Procedure for Determining Moisture Content

7. Standard Count for moisture
8. Moisture content of soil from gauge (%) 63.22
9. Check for moisture content [%(6 x 100%-100)] (%) 5.0

Take sample (about 4.5 kg) of material from area tested for density. **Procedure when sample contains less than 1/10 total weight in stone retained on 19.0 mm or 4.75 mm sieve**

10. Weight of 0.000943 m³ compacted wet soil + weight of container (kg)
11. Weight of 0.000943 m³ container
12. Weight of 0.000943 m³ compacted dry soil (kg)
13. Density of compacted wet soil (1060 x #12) (kg/m³)
14. Optimum moisture from dry density curve (Curve No. ) (%) 5.2
15. Maximum Dry Density (Curve No. ) TEST SECTION (kg/m³)
16. Amount above or below optimum moisture (%) 0.2
17. Compaction [%(6 x #15) x 100] (%) 101.2
17a Moisture from zero air voids curve using Line 6
18. Does material tested meet Specification requirements? Yes [ ] No [ ]
19. "A" Rolling ordered; "B" Averting ordered; "C" Watering ordered
20. Date Tested

* *In percent of Dry Density.
** Refer to C-9B-M, lines 28 - 38 when soil sample contains more than 1/10 total weight in stone retained on 19.0 mm or 4.75 mm sieve; Use No. 4 sieve for penetration method only.

Computed By: RANDY MORRIS Checked By: WOODY ANDERSON

DOT-1699

*Moisture reduced to obtain stability
**Figure 9-3. Example of C-135B Form**

**Nuclear Gauge Compaction Form**

```
STATE OF OHIO
DEPARTMENT OF TRANSPORTATION
NUCLEAR GAUGE COMPACTION FORM

Sample ID: 22223456-01
Personnel ID: 111-232-74
Date Sampled: 6/6/91

Type of Inspection: COMPACTION
Producer Code: 
Contractor: RAT CONSTRUCTION

Material Code: Test Results:

<table>
<thead>
<tr>
<th>Project/P.O.</th>
<th>P.O. Ind.</th>
<th>Item Code</th>
<th>Ref. Number</th>
<th>Item Code</th>
<th>Ref. Number</th>
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</thead>
<tbody>
<tr>
<td>833.90</td>
<td>310</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test of (check which): 
- Embankment
- Subgrade
- Base
- Other

Min. Compaction Req.: 98%

Test of (check which): 
- Limestone
- Gravel
- Slag
- Sandstone
- Granulated Slag
- Other

From Sta +10.00 +10.00 at feet (ft) or lt. of centerline to Sta +15.00 at feet (ft) or lt. of centerline, at approx. Elevation 100 ft

See Report No. (check which): Wet Dry

Maximum Density from Test Section 132 lb/ft³

Optimum Moisture 6322 %

98% of Max. Density 129.4 lb/ft³

Check Method used: 
- Direct Transmission
- Backscatter

Probe Depth inches

1. 1.
2. 2.
3. 3.
4. 4.
5. 5.
6. 6.

**Procedure for Determining Dry and Wet Density**

1. Station of test
2. Distance right or left of centerline if different than above (ft)
3. Approximate Elevation if different than above (ft)

<table>
<thead>
<tr>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
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<tbody>
<tr>
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<td>1522</td>
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<td></td>
<td></td>
<td></td>
<td>140.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>133.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Procedure for Determining Moisture Content**

1. Standard Count for moisture
2. Moisture content of soil from gauge (%) 63.22

<table>
<thead>
<tr>
<th>7.</th>
<th>8.</th>
<th>9.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Take sample (about 10 lb) of material from area tested for density.

**Procedure when sample contains less than 1/10 total weight in stone retained on 3/4" or No. 4 sieve**

1. Weight of 1/30 ft³ compacted wet soil + weight of container (lb)
2. Weight of 1/30 ft³ container (lb)
3. Weight of 1/30 ft³ compacted wet soil (#10 - #11) (lb)
4. Density of compacted wet soil (30 x #12) (lb/ft³)

<table>
<thead>
<tr>
<th>10.</th>
<th>11.</th>
<th>12.</th>
<th>13.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

14. Optimum moisture from dry density curve (Curve No. _)(%)
15. Maximum Dry Density (Curve No. _)(lb/ft³)

<table>
<thead>
<tr>
<th>14.</th>
<th>15.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>132.0</td>
</tr>
</tbody>
</table>

16. Amount above _ or below _ optimum moisture (#14 - #8)(%)
17. Compaction (#6 + #16) x 100 (%)

<table>
<thead>
<tr>
<th>16.</th>
<th>17.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>101.1</td>
</tr>
</tbody>
</table>

17a Moisture from zero air voids curve using Line 6

18. Does material tested meet Specification requirements? Yes _ No _
19. "A" Rolling ordered; "B" Aerating ordered; "C" Watering ordered
20. Date Tested

<table>
<thead>
<tr>
<th>18.</th>
<th>19.</th>
<th>20.</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

* In percent of Dry Density.

** Refer to C-86, lines 28 through 38 when soil sample contains more than 1/10 total weight in stone retained on 3/4" or No. 4 sieve; Use No. 4 sieve for penetration method only.

Computed By RANDY MORRIS

Checked By WOODY ANDERSON

DOT-1635

*Moisture reduced to obtain stability
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<tr>
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10.0 Earthwork Inspections, Tests, Reports, Controls, and Calculations

10.1 Inspection and Tests

Earthwork construction is controlled by inspection and tests to insure that the work is done in accordance with specification requirements. Detailed instructions on procedures for tests required to be made in the field are given in Chapter 3 to 9 of this manual.

Some tests of soil are normally made only in the Laboratory. Three laboratory tests which usually are performed on each soil sample are plastic limit, liquid limit and particle size analysis. This includes the determination of the percentages of silt and clay in the sample. Other laboratory soil tests which are performed as needed for special studies include the following: specific gravity, shrinkage, permeability, bearing ratio, unconfined compression, shear and consolidation. Description of test procedures for these tests are covered in ASTM and AASHTO publications. They are not included in this manual because detailed knowledge of these laboratory test procedures is not needed by field inspectors. Guidelines for sampling soil from cut or fill areas for submission to the Laboratory are contained in the Department’s Sampling and Testing Program.
10.2 Construction Controls and Final Earthwork Reports

The purpose of this section of the manual is to establish uniform practices in the administration of contracts involving earthwork and to give instruction on measurements required for construction control of earthwork. This section of the manual applies to all projects involving earthwork, regardless of whether or not borrow is involved.

Policy

Check measurements are made in areas where earthwork is being performed. A sufficient number of these checks are to be recorded in accordance with instructions in this manual to provide a satisfactory record of checks made. The purposes of these measurements and records are:

1. To insure that earthwork is being constructed to plan lines within specified tolerances.
2. To provide a simplified method of earthwork measurement so that payment may be based on corrected plan quantities, resulting in savings of engineering man hours required to arrive at pay quantities, and making possible more prompt final payment to the Contractor after completion of the work.

Measurement by Final Cross Sections

Final cross sections of roadway earthwork usually will not be required for any project provided the plan quantities are checked for accuracy and adequate checks have been made and recorded during construction to establish that plan quantities of earthwork have been performed within specified tolerances. However, final cross sections may be called for by the Bureau of Construction where, by inspection or other knowledge of the project, it is indicated that measurement by final cross section is necessary or desirable.

Procedure for Check Measurements and Check Calculations

1. Before earthwork construction is started, make plan-in-hand inspection to determine if the ground line conforms to the ground line shown on the plan cross sections, and if significant changes in topography indicate the need for additional cross sections at intermediate locations. Where this inspection indicates the need, arrange for further check by ground or aerial survey.
2. State on an appropriate form that this inspection has been made. Date and sign the form and place it in the project records.
3. Check accuracy of original ground lines shown on plan cross sections as follows:
   A. In order to verify the original ground lines shown on plan cross sections, the Engineer shall field check cross sections every 100 to 150 meters (300 to 500 feet) by either ground or aerial survey methods prior to the beginning of construction operations. If any appreciable variations from plan elevations are found, it will be necessary to take check sections at closer intervals in order to determine the extent of plan errors and amount of additional cross-sectioning required to provide accurate earthwork quantities. Use corrected ground line where plan cross section lines have been found in error.
   B. Plan quantities resulting from computations that have been properly documented and made a part of the project records are to be used as final pay quantities unless adjustments are necessitated by change orders. Any additions to, or deductions from, plan quantities necessitated by change orders shall be computed by project personnel in order to determine final pay quantities for adjusted items.
   C. Final pay quantities computed or adjusted by project personnel shall be
checked, either in the project office of the District office, by competent Department personnel who have been assigned to the project for construction control, supervision, etc.

D. All computations of adjustments shall be properly validated by the signed initials or names of persons who computated the adjusted pay quantities and those who performed the checking operations. Also, the dates that these functions were performed shall be indicated. These adjustment computations shall be made a part of the official project records.

4. Insure that slope stakes are set by the calculation method. The initial point for calculations should generally be a profile grade elevation.

5. Secure a copy of the survey notes, whether the staking is done by a Department or Contractor survey crew, and plot horizontal and vertical locations of slope stakes on black on white cross section sheets. Check accuracy of plan original ground cross sections at slope stake locations. Record errors noted and correct plan sections promptly.

6. Where the plan quantities have been checked and validated on the plans or on computation sheets provided by the design unit preparing the plans, it is not necessary during construction to make a detailed check of accuracy of plan earthwork quantities. If an error in validated plan quantities should be noted, recalculate the end areas and volumes in question. Where plan quantities have not been checked and validated on the plans or on computation sheets provided by the design unit preparing the plans, check all plan earthwork quantities for accuracy. Especially check locations where there are curves of short radius, such as ramps. Plan quantities frequently have been found to be in error by significant amounts at such locations. Where plan quantities are not correct, line out plan figures and write in correct figures. Check summary to see that quantities have been transferred accurately from cross section sheets.

7. Make check measurements during construction to insure work is being done within allowable field tolerances. Use project personnel for making these checks, supplemented by occasional use of the Department survey crew when needed. Make sufficient checks to insure that the work is being accomplished within allowable tolerances. The frequency of these check measurements should be determined by the Engineer.

8. Require corrections by the Contractor of all deviations from plan lines in excess of allowable tolerances as determined by check measurements. During rough grading, it is acceptable to permit cuts and fills to exceed tolerances by an amount which will be corrected during fine grading by practical construction methods. In the case of fills, require prompt correction of deviations inside allowable tolerances so that specified compaction of the outer edges will be obtained as the work progresses. In the case of deep cuts with steep slopes in rock or shale, require prompt correction of deviations in excess of allowable tolerances so that adjustments can be made, as the work progresses, while the slope areas in question are within reach of the equipment being used.

9. Record necessary check measurements in appropriate notebooks, inspectors report forms, or daily entry in the project diary stating location where check measurements were made.

10. Maintain in the project office a set of black on white prints of plan cross sections. Plot on these prints check measurements, changes and errors in plan lines.
11. On all projects where there is authorized work beyond plan lines, such as excavation of soft subgrade in cut, measurements of this authorized additional work are required.

12. For projects involving borrow as a pay item, measurements are required for:
   A. Borrow Material. Measurements required in accordance with 203.15(e).
   B. Suitable Excavation Wasted. This shall be deducted from borrow.
   C. Excess Fill. Made if excess fill exists after earthwork is completed.

Final cross sections are required if check measurements have not been adequate to establish that the earthwork has been performed to plan lines within specified tolerances.

**Personnel Required for Measurements**

Only use Department personnel to make all measurements of borrow. Contractor’s employees may be used to assist in check measurements and measurements of authorized excavations beyond plan lines where the quantity at each location is less than 1500 cubic meters (2,000 cubic yards). Providing collecting, plotting and calculating of the data and quantities is done by project personnel only. Examples of such authorized excavations are undercuts of soft subgrade in cut and required excavation in foundation for fills.

**Borrow Pay Quantity**

The quantity of borrow for payment is the measured borrow less suitable excavation wasted, less excess fill adjusted for shrinkage. General information on shrinkage is contained in Section 2.3. Use one of the following shrinkage factors adjustments:

1. Plan or shrinkage factor in Section 2.3.
2. Plan excavation used in embankment, plus actual measured borrow, divided by plan embankment plus excess fill.

\[
\text{Plan Excavation + Measured Borrow} \over \text{Plan Embankment + Excess Fill} = \frac{\text{Volume of Excavated Material}}{\text{Volume of Compacted Material}} = Shrinkage Factor
\]

3. Average Dry Density of the Borrow divided by the Average Dry Density of the fill.

The Engineer shall decide which shrinkage factors are to be used. Do not make additional measurements solely for the purpose of arriving at a refined shrinkage factor.

**Records**

Record all check measurements and check calculations on an appropriate form, date and sign or initial the form, and place it in the project records.

Records of check measurements shall be maintained up-to-date at the project office during construction and will be reviewed by the District Construction Administrator and the Central Office Representative during their routine visits to the project.

After completion of the earthwork, a tabulation of earthwork pay items shall be prepared showing plan quantities where applicable, and listing appropriate measured quantities for all areas where there was deviation from plan lines beyond specified tolerances which affect the pay quantities, showing total quantities for payment. This tabulation, together with records of check measurements, constitutes the earthwork report for the project, and after processing shall be filed in the District Office.
10.3 Earthwork Quantity Calculations

General
This section of the manual is intended to give a brief outline of the methods for determining earthwork quantities. Methods described in this section are acceptable for making this check.

Specification Basis
The specifications require that the average-end-area method to be used to determine volumes of earthwork for payment.

End Area Determinations
There are many acceptable methods for determining end areas for earthwork computations. Any method that will give accurate determinations may be used. Some of the most common methods for determining cross section end areas are as follows:

1. Planimeter. In this method, an instrument with a wheel and a graduated dial is run around the perimeter of a cross section and the area is found by multiplying the reading on the dial by a constant factor or by setting a factor on the planimeter and reading area directly from the planimeter dial.

2. Counting Squares. In this method, the number of unit squares in a section are counted. This is not practical for any but very small sections.

3. Stripping. This is a method of tallying unit squares by making successive marks on a strip of paper in a way to measure unit strips, accumulating all unit strips on a cross section, and converting to total cross section area. This method is simple and rapid, keeps the chance of error to a minimum.

4. Computer Method. In this method, data from cross sections, usually in coordinate form, is fed into a computer, which follows a program set up to finish areas and volumes.

5. Geometric Method. In this method, the section is broken into areas, such as triangles and trapezoids, and each area is calculated by geometry. The total area is found by adding the individual areas.

6. Arithmetic Calculation. This method uses information from a cross section (or field notes) which shows the elevation and distance from a base line for each break in the line which outlines the cross section, to calculate end areas using a formula. A pocket type calculator can be used for this calculation. Determination of cross section end areas by this method is exact, and any two persons using the same information (field notes), will obtain the same answer, providing no errors are made in the machine manipulation or arithmetical calculations. There is only one correct answer. Two methods are described and illustrated in Figures 10-1M (10-1) and 10-2M (10-2), either of which may be used.

Volume Determination
The end areas of English plans are detailed in square feet. The end areas of metric plans are detailed in square meters. Make the appropriate volume calculation shown below and on Figures 10-1M (10-1) and 10-2M (10-2).

Formula
For base lines and center lines on tangent, and for center lines on curves where the center line of the curve coincides with the center of mass (centroid) of the cross sections, the formula for computing volume from end areas are as follows:

\[ V = \frac{A \times A_1}{2} \times L ...............\text{Metric} \]
Where
\[ V = \text{volume in cubic meters} \]
\[ A = \text{cross section one end area in square meters} \]
\[ A_1 = \text{cross section other end area in square meters} \]
\[ L = \text{distance between } A \text{ and } A_1 \text{ in meters} \]
\[ V = \frac{A \times A_1}{2} \times \frac{L}{27} \text{ English} \]

Where
\[ V = \text{volume in cubic yards} \]
\[ A = \text{cross section one end area in square feet} \]
\[ A_1 = \text{cross section other end area in square feet} \]
\[ L = \text{distance between } A \text{ and } A_1 \text{ in feet} \]

Table
Figure 10-3 shows a table for use in determining cubic yards from the sum of end areas for sections 100 feet apart, and for conditions described above. This table cannot be used on metric projects.

Volume Determination on Curves
Where cross sections are at right angles to center lines on curves, and the center line is not located at the center of mass (centroid) of the cross sections, corrections must be applied to volume calculations to secure an accurate result. Especially on curves of short radius, such as commonly used on ramps, inaccuracies of considerable magnitude may result unless proper corrections have been used in calculating earthwork volumes. Methods in general use for determining accurate quantities in such cases include the following:

1. Determine the distance between centroids of adjacent cross sections, and use this distance, rather than the center line distance between cross sections, to calculate earthwork volume. Location of the centroid for any cross section may be readily determined by computer. Handbooks and textbooks on civil engineering give formulas and detailed instructions for making such calculation.

2. Locate centroids of adjacent cross sections using one of the methods described in (1). Calculate a corrected arc length between sections as illustrated in Figure 10-4. Use corrected arc length to compute volume.

3. A computer program may be available for use in making volume calculations. Arrangements for use of this program may be made through the Construction Administrator.

4. Use a reproducible base line along the area in question, and use cross sections at right angles to the base line for quantity calculations as described above.

5. Figure 10-4 is labeled both meters and feet. You may insert feet or meters and the calculations will be the same. No conversion was made in the numerical values.
10.4 Check List for Earthwork Calculations

1. Make and document plan in hand check ........ 10.2
2. Obtain intermediate cross sections if needed 10.2
3. Plot slopestakes ........................................ 10.2
4. Check accuracy every 90 to 150m (300 to 500 feet) of original ground lines shown on plan cross sections. Correct cross section ground lines found to be in error ........................................ 10.2
5. Check to see if plan quantities have been checked and validated. If not, check plan quantities ........ 10.2
6. Inspect plans to insure quantities on short radius curves have been correctly computed ........ 10.3
7. Require correction of unstable foundation areas ................................................................. 2
8. Measure and document undercut areas ........ 10.2
9. Secure from the Contractor his plan for proposed borrow and waste areas, and written permission from property owners involved in waste. A storm water permit may be required ...................... 2
10. Assign inspectors to make and record slope checks regularly ........................................... 10.2
11. Check assignments to insure that earthwork in all areas is inspected ......................................... 10.2
12. Check that sufficient moisture and density tests are being made for adequate coverage of embankment and subgrade compaction ........ 2
13. Require correction of slopes found to be in error ................................................................ 10.2
14. Insure that erosion control procedures are in accordance with specification requirements .... 2
15. Test roll subgrade where called for by contract ....................................................................... 2
16. Require correction of unstable subgrade .......... 2
17. Check subgrade for specification requirements for moisture, density, grade and cross section .......... 2
18. Establish subbase density requirements for test section ......................................................... 9
19. Check that sufficient moisture and density tests are being made for adequate coverage of subbase compaction .......................................................... 9
20. Insure adequate samples are taken to represent subbase pay quantity ........ 700 Specifications
21. Insure that adequate number of checks for depth of subbase are being made and documented .... 9
Procedure: Select a base line either at or below the lowest elevation of the cross section. The equation for the area of the cross section for this example is as follows:

\[
\text{Exact Area} = L_1 \frac{[a+b]}{2} + L_2 \frac{[b+c]}{2} - L_3 \frac{[c+d]}{2} - L_4 \frac{[d+e]}{2} - L_5 \frac{[e+f]}{2} - L_6 \frac{[f+g]}{2} - L_7 \frac{[g+h]}{2} - L_8 \frac{[h+i]}{2} - L_9 \frac{[i+g]}{2}
\]

Using a base line of 810.0 the area is:

\[
= 8.2 \left(\frac{10.2+10.5}{2}\right) + 7.3 \left(\frac{10.5+11.2}{2}\right) - 4.6 \left(\frac{11.2+7.8}{2}\right) - 0.3 \left(\frac{7.8+7.8}{2}\right) - 0.6 \left(\frac{7.8+8.1}{2}\right) - 6.1 \left(\frac{8.1+8.1}{2}\right) - 0.6 \left(\frac{8.1+7.8}{2}\right) - 2.1 \left(\frac{7.8+9.3}{2}\right) - 1.2 \left(\frac{9.3+10.2}{2}\right)
\]

\[
= 8.2 (10.35) + 7.3 (10.85) - 4.6 (9.5) - 0.3 (7.8) - 0.6 (7.95) - 6.1 (8.1) - 0.6 (7.95) - 2.1 (8.55) - 1.2 (9.75) = 29.43 \text{ m}^2
\]

Figure 10-1M. End Area Determination Method 1
Procedure: Select a base line either at or below the lowest elevation of the cross section. The equation for the area of the cross section for this example is as follows:

\[
\text{Exact Area} = L_1 \frac{[a+b]}{2} + L_2 \frac{[b+c]}{2} - L_3 \frac{[c+d]}{2} - L_4 \frac{[d+e]}{2} - L_5 \frac{[e+f]}{2} - L_6 \frac{[f+g]}{2} - L_7 \frac{[g+h]}{2} - L_8 \frac{[h+i]}{2} - L_9 \frac{[i+a]}{2}
\]

Using a base line of 810.0 the area is:

\[
27 \frac{[11+12]}{2} + 24 \frac{[12+14]}{2} - 15 \frac{[14+3]}{2} - 1 \frac{[3+3]}{2} - 2 \frac{[3+4]}{2} - 20 \frac{[4+4]}{2} - 2 \frac{[4+3]}{2} - 7 \frac{[3+8]}{2} - 4 \frac{[8+11]}{2}
\]

Or:

\[
\text{Exact Area} = (27 \times 11.5) + (24 \times 13) - (15 \times 8.5) - (1 \times 3) - (2 \times 3.5) - (20 \times 4) - (2 \times 3.5) - (7 \times 5.5) - (4 \times 9.5) = 321.5 \text{ sq. ft}
\]

Figure 10-1. End Area Determination Method 1
Procedure: Select the starting point, normally at the extreme left, and list the plotted coordinates in counterclockwise sequence. For this example:

\[
\begin{array}{cccccccc}
50.2 & 49.3 & 47.8 & 48.1 & 47.8 & 47.8 \\
4.9 & 6.1 & 8.2 & 8.8 & 14.9 & 15.5 & 15.8 \\
51.2 & 50.5 & 50.2 \\
20.4 & 13.1 & 4.9
\end{array}
\]

Multiply and accumulate the products of the denominator and the adjacent numerator to the right as follows:

\[
4.9 \times (49.3) + 6.1 \times (47.8) + 8.2 \times (48.1) + 8.8 \times (48.1) + 14.9 \times (47.8) + 15.5 \times (47.8) \\
+ 15.8 \times (51.2) + 20.4 \times (50.5) + 13.1 \times (50.2) = 5300.75
\]

Multiply and accumulate the products of the denominator and the adjacent numerator to the left as follows:

\[
4.9 \times (50.5) + 13.1 \times (51.2) + 20.4 \times (47.8) + 15.8 \times (47.8) + 15.5 \times (48.1) \\
14.9 \times (48.1) + 8.8 \times (47.8) + 8.2 \times (49.3) + 6.1 \times (50.2) = 5241.89
\]

\[\text{Exact Area} = \frac{5300.75 - 5241.89}{2} = 29.43 \, m^2\]

Figure 10-2M. End Area Determination Method 2
Procedure: Select the starting point, normally at the extreme left, and list the plotted coordinates in counter-clockwise sequence. For this example:

\[
\begin{array}{ccccccccccc}
  21 & 18 & 13 & 14 & 14 & 13 & 13 & 24 & 22 & 21 \\
  16 & 20 & 27 & 29 & 49 & 51 & 52 & 67 & 43 & 16
\end{array}
\]

Multiply and accumulate the products of the denominator and the adjacent numerator to the right as follows:

\[
(16 \times 18) + (20 \times 13) + (27 \times 14) + (29 \times 14) + (49 \times 13) + (51 \times 13) + (52 \times 24) + (67 \times 22) + (43 \times 21) = 6257 \text{ sq. ft.}
\]

Multiply and accumulate the products of the denominator and the adjacent numerator to the left as follows:

\[
(16 \times 22) + (43 \times 24) + (67 \times 13) + (52 \times 13) + (51 \times 14) + (49 \times 14) + (29 \times 13) + (27 \times 18) + (20 \times 21) = 5614 \text{ sq. ft.}
\]

\[
\text{Exact Area} = \frac{6257 - 5614}{2} = 321.5 \text{ sq. ft.}
\]

**Figure 10-2. End Area Determination Method 2**
### CUBIC YARDS FOR SUM OF END AREAS

**LENGTH OF PRISM 100 FEET**

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<td>955</td>
<td>1024</td>
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</table>

#### Explanation:

**Find sum of end areas in body of table. Then at top or bottom of vertical column find hundreds of cubic yards and at extreme right or left of horizontal line find cubic yards below 100.**

**Example:** $A_1 = 420^\circ$, $A_2 = 472^\circ$, $\text{Sum} = 892^\circ$, which is found under 16 hundred and to the right or left 52.

**Answer:** 1682 cubic yards.

---

**Figure 10-3. Cubic Yards for the Sum of End Areas**

**Figure not converted to metric**
Assume a curve with a radius of 572.96 (meters or feet). Centroid at Station 0 is found to be 35 (meters or feet) from the centerline and the centroid at Station 0 + 50 is found to be 25 (meters or feet) from the centerline.

Correct radius between centroids is therefore 572.96 (meters or feet) minus \([35 + 25 ÷ 2]\) or 542.96 (meters or feet). The alignment factor is then 542.96 ÷ 572.96 or 0.94764 which, when multiplied by 50 (meters or feet) gives a corrected arc length between centroids of 47.38 (meters or feet).

Figure 10-4. Example of Procedures for Determining Corrected Arc Length Between Centroids
Curve to the left was used in Figure 10-4. If the curve had been to the right (as above) the correct radius between centroids would be 572.96 (meters or feet) plus \([(35 + 25) ÷ 2]\) or 602.96 (meters or feet).

The alignment factor would be 602.96 ÷ 572.96 or 1.05236 which, when multiplied by 50 (meters or feet) gives a corrected arc length between centroids of 52.62 (meters or feet).

**Figure 10-5. Corrected Arc Length With a Curve to the Right**
Notes
11.0 Documentation

It is the intent of this section to recommend minimum documentation requirements by combining and/or eliminating various daily inspection forms now in use, and still document information in sufficient detail to verify that construction is in substantial conformity with the proposal, plans and specifications.

Item 201 Clearing and Grubbing

Form
CMS-1 Inspector’s Daily Report
CMS-1 Calculations, Sketches, etc. - Reverse side of CMS-1

Pay Units - Lump Sum
Clearing and Grubbing
Verify that clearing and grubbing is sufficient to permit construction in accordance with plan.

Pay Units - Each
Trees or stumps removed
Trees 0.3m (12 inches) and less in diameter will be classed as brush
All trees over 0.30m (12 inches) in diameter 1.5m (measured 54 inches above the ground) shall be measured in accordance with schedule in 201.05. Stumps shall be measured by the average diameter at the cutoff.

Pay Units - Lump Sum
Structures Removed
Verify that removal is in accordance with plan.

Pay Units - Lump Sum
Portions of Structures Removed

Pay Units - Lump Sum
Verify Conformance with plan.

Cubic meter (Yard)
Portions of Structures Removed

or

Kilogram (Pound)
Portions of Structures Removed

Cubic meter (Yard)
Field measurement before removal or verified plan.

Kilogram (Pound)
Dimensions to nearest cubic yard. Weight to nearest 50 kilograms (100 pounds) from validated weight tickets or weights calculated from verified plan dimensions.

Linear meter (Foot)
Pipe removed for re-use or storage

Linear meter (Foot)
Pipe removed. Field measured to nearest foot and verify as to re-use, storage or disposed of.

Square meter (Yard)
Pavement Removed

Square meter (Yard)
Wearing Course Removed

Square meter (Yard)
Base Removed

Square meter (Foot)
Walk Removed

Field measurement and calculation of area to nearest (square meter, square foot or square yard)

Item 202 Removal of Structures and Obstructions

Form
CMS-1 Inspector’s Daily Report
Calculations, Sketches, etc. - Reverse side of CMS-1
<table>
<thead>
<tr>
<th>Linear meter (Foot)</th>
<th>Curb Removed</th>
<th>Documentation of Proof Rolling Time Earthwork Calculation Sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear meter (Foot)</td>
<td>Curb and Gutter Removed Field measurement to nearest 0.1 meter (foot)</td>
<td></td>
</tr>
<tr>
<td>Linear meter (Foot)</td>
<td>Curb Removed for Storage Field measured to nearest 0.1 meter (foot) and verify as to storage.</td>
<td></td>
</tr>
<tr>
<td>- Lump Sum</td>
<td>Buildings Removed Verify that removal is in accordance with plan.</td>
<td></td>
</tr>
<tr>
<td>- Each</td>
<td>Underground Storage Tank Removed</td>
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</tr>
<tr>
<td>- Each</td>
<td>Regulated Underground Storage Tank Removed</td>
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</tr>
<tr>
<td>- Each</td>
<td>Septic Tank Removed</td>
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<tr>
<td>- Each</td>
<td>Privy Vault Removed Field count of number removals in accordance with plan.</td>
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<tr>
<td>Linear meter (Foot)</td>
<td>Guardrail Removed</td>
<td></td>
</tr>
<tr>
<td>Linear meter (Foot)</td>
<td>Guardrail Removed for Re-use or Storage</td>
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</tr>
<tr>
<td>Linear meter (Foot)</td>
<td>Fence Removed for Re-Use or Storage Field measured to nearest 0.1 meter (foot) and verify as to re-use, storage or disposed of.</td>
<td></td>
</tr>
<tr>
<td>- Each</td>
<td>Temporary Drums Removed</td>
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<td>- Each</td>
<td>Manhole Removed</td>
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<tr>
<td>- Each</td>
<td>Manhole Abandoned</td>
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<tr>
<td>- Each</td>
<td>Catch Basin or Inlet Removed</td>
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<tr>
<td>- Each</td>
<td>Catch Basin or Inlet Abandoned Field count of number removed or abandoned in accordance with plan.</td>
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</tbody>
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**Item 203 Roadway Excavation and Embankment Form** CMS-1 Inspector’s Daily Report Calculations, Sketches, etc. - Reverse side of CMS-1

**Note:** Earthwork calculations can be documented on project plan x-sections, with colored pencil

- C-88M (C-88) Report on Compaction
- C-89M (C-89) Report on Compaction Using Cylinder Method
- C-135B-M (C-135B) Report on Compaction Using a Nuclear Gauge
- C-90M (C-90) Report on Density of Granular Material

**Pay Units**

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<th>Excavation Including Embankment Construction Calculated from Verified Cross Sections.</th>
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</thead>
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<td>Excavation Not Including Embankment Construction Calculated from Verified Cross Sections. When Cross Sectioning is impractical, Three Dimensional Measurements Shall be Used.</td>
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<tr>
<td>Cubic meter (Yard)</td>
<td>Borrow When in a Natural Formation, Calculated From Verified Cross Sections.</td>
</tr>
<tr>
<td>Metric Ton (Ton)</td>
<td>Calculated From Weight Tickets, using a Field Determined Shrinkage Factor</td>
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<tr>
<td>Station or Linear Grading (Kilometer)</td>
<td>Calculated From Verified Length Measurement to 0.1 Station or kilometer (mile)</td>
</tr>
<tr>
<td>Square meter (Yard)</td>
<td>Subgrade Compaction Calculated From Verified Areas of Pavement, Paved Median, Paved Shoulders and Curb and Gutter Supported by the Compacted Subgrade.</td>
</tr>
</tbody>
</table>
### Item 207  Temporary Soil Erosion and Sediment Control

**Form**  CMS-1 Inspector’s Daily Report  
Calculations, Sketches, etc. - Reverse side of CMS-1  
Seeding Calculation Sheet  

**Note:** Seeding calculations can be documented on project plan x-section sheets, with colored pencil  

**Pay Units**  
- Square Meters (Yard)  
  Temporary Seeding and Mulching  
  Verified field measurement.  
- Linear Meters (Foot)  
  Temporary Slope Drains  
  Verified field measurement.  
- Cubic Meters (Yard)  
  Temporary Benches, Dikes, Dams, and Sediment Basins  
  Calculated from cross sections or three-dimensional measurement.  
- Each Straw or Hay Bales  
  Field counted and staked in place.  
- Linear Meters (Foot)  
  Filter Fabric Fence  
  Field measured in place supported on fence.

### Item 310  Subbase, Item 304 Aggregate Base

**Form**  CMS-1 Inspector’s Daily Report  
Calculations, Sketches, etc. - Reverse side of CMS-1  
C-90M (C-90)  Report on Density of Granular Material  
C-135B-M (C-135B)  Report on Compaction Using a Nuclear Gauge  

**Pay Unit**  
- Cubic Meter (Yard)  
  Calculated from Verified Plan Dimensions, compacted in place.

### Item 601  Slope and Channel Protection

**Form**  CMS-1 Inspector’s Daily Report  
Reverse Side of CMS-1, Calculations, Sketches, etc.  
TE-45 Concrete Inspector’s Daily Report  

**Pay Unit**  
- Square meter (Yard) - Riprap  
  Field measurement of actual surface area in place.  
- Square meter (Yard) - Crushed Aggregate Slope Protection  
  Field measurement of actual surface area in place.  
- Square meter (Yard) - Concrete Slope Protection  
  Field measurement of actual surface are in place.  
- Cubic meter (Yard) - Dumped Rock Fill Type  
  Calculated from verified plan dimensions; or measured loose in the vehicle; or conversion of weight tickets.  
- Cubic meter (Yard) - Rock Channel Protection, Type _________ with bedding  
  Same as dumped rock fill.  
- Cubic meter (Yard) - Rock Channel Protection, Type _________ without bedding  
  Same as dumped rock fill.  
- Linear meter (Foot) - Paved Gutter  
  Field measurement of length of gutter in place.
### Item 603  Pipe Culverts and Drains

**Form** CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

**Pay Unit**
- Linear meter (Foot) - _______” Conduit, Type ______
- Linear meter (Foot) - _______” x _______” Conduit, Type ______
- Linear meter (Foot) - _______” Conduit Reconstructed, Type ______

Field measurement of actual length (to nearest 0.1 meter (foot) of conduit in place, including bends and branches. Measurement shall be from center to center of catch basins, inlets or manholes.

### Item 605  Underdrains

**Form** CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

**Pay Unit**
- Linear meter (Foot) - ___________” Unclassified Pipe Underdrains
- Linear meter (Foot) - ___________” Shallow Pipe Underdrains
- Linear meter (Foot) - ___________” Deep Pipe Underdrains

Field measurement of actual length of pipe in place.

### Item 615  Temporary Roads and Pavements

**Form** CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

- C-146 Bituminous Concrete Inspection
- C-90M (C-90) Report on Density of Granular Material
- C-135B-M (C-135B) Report on Compaction Using a Nuclear Gauge
- TE-45 Concrete Inspector’s Daily Report
- TE-38 Report on Concrete Beams

**Pay Unit**
- Square meter (Yard) - Temporary Pavement, Class A
- Square meter (Yard) - Temporary Pavement, Class B

Field measurement of actual area of pavement in place, maintained and removed as directed. Refer to Flexible Pavements Manual and Rigid Pavements Manual.

**Lump Sum** Temporarily Roads Built in accordance with plan dimensions, maintained and removed as directed. Aggregate shall be paid for under 410 and calcium shall be paid for under 616.

### Item 616  Dust Control

**Form** CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

**Pay Unit**
- Cubic meters (M Gallons) - Water Quantity in cubic meters (thousands of gallons) from tanks of predetermined capacity, by means of accepted meters or weight conversion.
- Metric tons (Tons) - Calcium Chloride Number of metric tons (tons) by weight measurement. When brine is used the metric tons (tons) of calcium chloride shall be determined by multiplying the number of gallons by the factor 0.0024.
### Item 617  Reconditioning Shoulders

**Form** CMS-1 Inspector’s Daily Report  
Reverse side of CMS-1, Calculations, Sketches, etc.

**C-90M (C-90) Report on Density of Granular Material**

**C-135B-M (C-135B) Report on Compaction Using a Nuclear Gauge**

**Pay Unit**
- **Square meter** (Yard) - Shoulder Preparation  
  Field measurement of actual area of shoulder compacted in place.
- **Cubic meter** (Yard) - Compacted Aggregate  
  Calculated from verified plan dimensions, compacted in place. In the case of variable width and depth, conversion of weights given in 617.06.
- **Cubic meters** (M Gallons) - Water  
  Quantity in cubic meters (thousands of gallons) by means of approved meters or from calibrated tanks.

### Item 651  Topsoil Stockpiles

**Form** CMS-1 Inspector’s Daily Report  
Reverse side of CMS-1, Calculations, Sketches, etc.

**Pay Unit**
- **Cubic meters** (Yard) - Topsoil Stockpiled  
  Calculate volume before removal or from verified plan dimensions.

### Item 652  Placing Stockpiled Topsoil

**Form** CMS-1 Inspector’s Daily Report  
Reverse side of CMS-1, Calculations, Sketches, etc.

**Pay Unit**
- **Square meter** (Yard) - Seeding and Renovating Existing Sod  
  Field measurement of the actual area of sod seeded and renovated.
Metric ton (Ton) - Commercial Fertilizer
Calculated to nearest 0.1 metric ton (ton) from validated weights.

**Item 656 Roadside Cleanup**

**Form** CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

**Pay Unit**
Square meters (M Square Feet) - Roadside Cleanup
Field measurement of the actual area cleaned up (outside of the excavated and filled areas), calculated to the nearest 500 square meters (thousand square feet).

**Item 657 Riprap for Tree Protection**

**Form** CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

**Pay Unit**
Square meters (Yard) - Riprap for Tree Protection
Field measurement of the actual area of riprap of the specified thickness in place, measured to the face of the wall or walls.

**Item 658 Tree Root Aeration**

**Form** CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

**Pay Unit**
Cubic meters (Yard) - Tree Root Aeration
Calculate volume in carrier at work site.

**Item 659 Seeding and Mulching**

**Form** CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

**Note:** Seeding could be calculated and documented on project plan x-section sheets (in colored pencil).

**Pay Unit**
Metric ton (Ton) - Commercial Fertilizer
Metric ton (Ton) - Agricultural Limestone
Calculate to the nearest 0.1 metric ton (ton), using square meters (yards) times the specified rate of application.

Square meters (Yard) - Seeding and Mulching
Field measurement of the actual area seeded and mulched in accordance with specifications.

Square meters (Yard) - Repair Seeding and Mulching
Field measurement of the actual area reshaped, seeded and mulched as determined by the Engineer.

Cubic meters (M Gallons) - Water
Quantity in cubic meters (thousands of gallons) by means of approved meters from calibrated tanks.

Square meters (M Square Feet) - Mowing
Field measurement of actual area mowed and calculated to the nearest 500 square meters (thousand squarefoot).

**Item 660 Sodding**

**Form** CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.
Item 661  Planting Vines

Form  CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

Pay Unit  Each  Planting Vines
Actual number of vines planted and mulched, in place.

Item 662  Planting Shrubs

Form  CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

Pay Unit  Each  Planting Shrubs
Actual number of shrubs planted and mulched, in place.

Item 663  Planting Trees

Form  CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

Pay Unit  Each  Planting Trees
Actual number of each species or variety of trees in place.

Item 664  Planting Salvaged Plants

Form  CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

Pay Unit  Each  Planting Salvaged Plants
Actual number of vines, shrubs and trees in place.

Item 665  Large Trees Moved and Reset

Form  CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

Pay Unit  Each  Large Trees Moved and Reset
Actual number of trees moved and reset or those furnished, in place.

Cubic meters  (Yard) - Aggregate for drain pits and tree holes.
Calculate volume in carrier at work site.

Item 666  Pruning Existing Trees

Form  CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.

Pay Unit  Each  Pruning Existing Trees,
80 to 200 mm (3 to 8 in.) Diameter.
- Each  Pruning Existing Trees,
200 to 400 mm (8 to 16 in.) Diameter.
- Each  Pruning Existing Trees,
400 to 600 mm (16 to 24 in.) Diameter.
- Each  Pruning Existing Trees,
600 to 900 mm (24 to 36 in.) Diameter.
- Each  Pruning Existing Trees,
900 mm (36 in.) and over
Actual number of trees, according to size.

Item 667  Seeding and Jute Matting

Form  CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.
Pay Unit
Square meter (Yard) Seeding and Jute Matting
Field measurement or ground surface area of seeding and jute matting in place.

Item 668 Seeding and Excelsior Matting
Form CMS-1 Inspector’s Daily Report
Reverse side of CMS-1, Calculations, Sketches, etc.
Pay Unit
Square meter (Yard) - Seeding and Excelsior Matting
Field measurement of ground surface area of seeding and excelsior matting in place.
12.0 Blank Forms Index

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<tr>
<th>Form</th>
<th>Description</th>
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<td>CMS-1</td>
<td>Inspectors Daily Report</td>
</tr>
<tr>
<td>C-169</td>
<td>Earthwork Calculations</td>
</tr>
<tr>
<td>C-168</td>
<td>Seeding Calculations</td>
</tr>
<tr>
<td>C-167</td>
<td>Documentation Record of Proof Rolling Time</td>
</tr>
<tr>
<td>C-166</td>
<td>Work Sheet for Moisture-Density Ohio Typical Density Curves Metric (English)</td>
</tr>
<tr>
<td>C-88-M</td>
<td>Report on Compaction (Metric)</td>
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<td>C-88</td>
<td>Report on Compaction</td>
</tr>
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<td>C-89-M</td>
<td>Report on Compaction (Cylinder Density Method) (Metric)</td>
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<tr>
<td>C-89</td>
<td>Report on Compaction (Cylinder Density Method)</td>
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<td>C-90-M</td>
<td>Report on Density of Granular Material (Metric)</td>
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<td>C-90</td>
<td>Report on Density of Granular Material</td>
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<td>C-135B-M</td>
<td>Report on Compaction Using the Nuclear Gauge (Metric)</td>
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<td>C-135B</td>
<td>Report on Compaction Using the Nuclear Gauge</td>
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<td>C-171</td>
<td>Report on Compaction Using the Nuclear Gauge with an Aggregate Correction</td>
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<td>C-172</td>
<td>Item 307 Non-Stabilized Drainage Base Compaction Form</td>
</tr>
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**State of Ohio**  
**Department of Transportation**  
**INSPECTOR’S DAILY REPORT**

**Project No. ___ - __________ Co./Rt./Sec.____________________ Diary Date ________________ I.D.R. # __________

☐  Check if additional sheet required.  

Page ____ of ____

## CONTRACTOR’S HOURS WORKED AND NUMBER OF EMPLOYEES

<table>
<thead>
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<th>Contractor</th>
<th>Supt./Foreman</th>
<th>Hours</th>
<th>Number of Employees</th>
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Description of Work:

________________________________________________________________________

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Description of Work:

________________________________________________________________________

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Description of Work:

________________________________________________________________________

## CONTRACTOR’S EQUIPMENT

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## EMPLOYEE DATA

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<th>Work Code</th>
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*OT Explanation: ____________________

DOT-1633
### PAY ITEMS

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<th>Description of Work</th>
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<th>Quantity or Lump Sum Amount</th>
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### GENERAL REMARKS

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### SPECIAL NOTES

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P.E./P.S. Initials: ___________________________  Inspector’s Signature: ___________________________
# EARTHWORK CALCULATIONS

## Calculations Details

- **County**: 
- **S.R.**
- **Sec.**
- **Road**: 
- **Date**: 

## Calculations Table

### CUTS

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### FILLS

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# Seeding Calculations

**STATE OF OHIO**  
DEPARTMENT OF TRANSPORTATION

## Calculations

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Calculated by: __________________________  Checked by: __________________________

Road: __________________________  Date: __________________________

County: __________________________  S.R.: __________________________  Sec.: __________________________
TOTAL WEIGHT OF ROLLER___________ Metric Tons (tons) TIRE PRESSURE___________ kPa (P.S.I.)

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<th>STATION TO STATION</th>
<th>LANE OR LOCATION</th>
<th>REMARKS</th>
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AREAS TO CORRECT

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* TOTAL OF TODAY'S TIME _______ HOURS ________ MINUTES (TO NEAREST 6).

SIGNATURE OF STATE REPRESENTATIVE__________________________________ DATE_______________________
SIGNATURE OF CONTRACTOR'S REPRESENTATIVE____________________________ DATE_______________________

*RECORD TO NEAREST 0.10 HOUR-SPEC. 203.15(g)

NOTE: USE SEPARATE SHEET EACH DAY.
<table>
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<tr>
<th>Wt. of Compacted Sample + Container Kg (lbs.)</th>
<th>Wt. of Sample Kg/m³ (lbs. per cu. ft.)</th>
<th>Wt. of Sample Kg (lbs.)</th>
<th>Penetration and Resistance</th>
<th>Moisture Determination</th>
<th>Dry Wt. of Soil Kg/m³ (lbs. per cu. ft.)</th>
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<td>Size, mm² (sq. in.)</td>
<td>Reading N (lbs.)</td>
<td>Pressure mPa (lbs. per sq. in.)</td>
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Max. Dry Wt. ____________________ Kg/m³ (lbs./cu. ft.)
Opt. Moisture __________________%
Ohio Typical Density Curves (Metric)

Moisture - Percent of Dry Weight

Kilograms per cu. meter (wet weight)

Mega Pascals (MPa)

Typical Moisture Density Curves
Set "C"

Originally Prepared by the Ohio State Highway Testing and Research Laboratory from results of tests on 10,000 Ohio soil samples

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<th>Curve</th>
<th>Max. dry wt. kg/m³</th>
<th>Optimum Moisture</th>
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Penetration Resistance Curves

* Computer re-drawn February 1996

Ohio Typical Density Curves (Metric)
**State of Ohio**

**Department of Transportation**

**Report on Compaction**

Sample ID: ____________________ Personnel ID: ____________________ Date Sampled: __/__/____

Type of Inspection: ______________ Producer Code: ______________ Contractor: ______________

Material Code: ______________ Test Results: ______________

<table>
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<tr>
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</tr>
</thead>
</table>

Test of (check which): ☐ Embankment ☐ Subgrade ☐ Base ☐ Other ____________ Min. Compaction Req.: ____________ %

From Sta ______ + ______ at ______ meters ______ (ft. or lt.) of centerline, at approx. Elevation ______ m

Read: "Manual of Procedures for Earthwork"

1. Weight of wet soil (& stone, if any) from auger hole + weight of container ______ kg
2. Weight of container ______ kg
3. Weight of wet soil (& stone, if any) from auger hole (#1 less #2) ______ kg

4. Weight of 0.000943 m³ compacted wet soil + weight of container ______ kg
5. Weight of 0.000943 m³ container ______ kg
6. Weight of 0.000943 m³ compacted wet soil (#4 less #5) ______ kg
7. Density of compacted wet soil (1060 X #6) ______ kg/m³

8. **Average penetration reading (3 or more tests) using ______ mm² needle ______ N
9. **Average penetration resistance (#8 + end area of needle) ______ MPa
10. Optimum moisture from Dry Weight Curve (Curve No. ______) ______ %
11. Moisture from Wet Weight Curve (Curve No. ______) or by drying ______ %
12. Amount above Ø or below Ø optimum moisture (difference #10 & #11) ______ %

13. Weight of sand + weight of density-cone apparatus ______ kg
14. Weight of density-cone apparatus ______ kg
15. Weight of sand in density-cone apparatus (#13 less #14) ______ kg
16. Volume of density-cone apparatus (recorded on density-cone) ______ m³
17. Density of sand (#15 + #16) ______ kg/m³
18. Weight of density-cone and remaining sand after cone is filled on leveled area ______ kg
19. Weight of sand required to fill cone on leveled area (#13 less #18) ______ kg
20. Weight of density-cone and remaining sand after filling auger hole & cone ______ kg
21. Weight of sand in auger hole & cone (#18 less #20) ______ kg
22. Weight of sand in auger hole (#21 less #19) ______ kg
23. Volume of auger hole (#22 + #17) ______ m³

**Procedure when sample contains less than 1/10 total weight in stone retained on 19.0 mm or 4.75 mm sieve***

24. Density of wet soil in fill (#3 ÷ #23) ______ kg/m³
25. Density of dry soil in fill [(100 x #24) ÷ (100 + #11)] ______ kg/m³
26. Max. dry density (From Curve No. ______) ______ kg/m³
27. Compaction (#25 ÷ #26 x 100) ______ %

**Procedure when sample contains more than 1/10 total weight in stone retained on 19.0 mm or 4.75 mm sieve***

28. Weight of Sample (#3) ______ kg
29. Weight of stone removed from sample and retained on 19.0 mm or 4.75 mm sieve ______ kg
30. Percent stone in sample (#29 ÷ #28 x 100) ______ %
31. Weight of stone in one cubic meter of material (#24 x #30 ÷ 100) ______ kg
32. Volume of stone in one cubic meter of material [#31 + (Sp. Gr. x 1000)] ______ m³
33. Volume of wet soil in one cubic meter of material (1.00 less #32) ______ m³
34. Weight of wet soil in one cubic meter of material (#24 less #31) ______ kg
35. Density of wet soil (#34 ÷ #33) ______ kg/m³
36. Density of dry soil (#35 x 100) ÷ (#11 + #10) ______ kg/m³
37. Compaction with stone removed (#36 ÷ #25 x 100) ______ %
38. Moisture from zero air voids curve using (#25 or #36) ______ %

*Average Specific Gravity Values: Limestone = 2.6; Gravel = 2.5; Sandstone and Sandy Shale = 2.2

**Use this method only as a last resort.

***Use 4.75 mm sieve for penetration method only.

Does material tested meet specification requirements for: (write yes or no on each of following)

Max. dry weight ______; Moisture ______; Compaction ______

Does test check zero air voids curve (check which): Yes ☐ No ☐

Action taken by (check which): ☐ Inspector or ☐ Project Engineer

If material tested does not meet specification requirements:

☐ Additional rolling ordered ☐ Aeration ordered ☐ Watering ordered ☐ Other

Computed By ____________________ Checked By ____________________

DOT: 1616
Sample ID: [Blank]  Personnel ID: [Blank]  Date Sampled: [Blank]  
Type of Inspection: [Blank]  Producer Code: [Blank]  Contractor: [Blank]  
Material Code: [Blank]  Test Results: [Blank]  

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<th>P.O. Ind.</th>
<th>Item Code</th>
<th>Ref. Number</th>
<th>Item Code</th>
<th>Ref. Number</th>
</tr>
</thead>
</table>

Test of (check which): [ ] Embankment [ ] Subgrade [ ] Base [ ] Other [ ] Min. Compaction Req. ______%  
From Sta ______ + ______ at ______ feet (rt. or ft.) of centerline, at approx. Elevation ______ ft  

Read: "Manual of Procedures for Earthwork"  
1. Weight of wet soil & stone, if any) from auger hole + weight of container ______ lb  
2. Weight of container ______ lb  
3. Weight of wet soil & stone, if any) from auger hole (#1 less #2) ______ lb  
4. Weight of 1/30 ft³ compacted wet soil + weight of container ______ lb  
5. Weight of 1/30 ft³ container ______ lb  
6. Weight of 1/30 ft³ compacted wet soil (#4 less #5) ______ lb  
7. Density of compacted wet soil (30 X #6) ______ lb/ft³  
8. **Average penetration reading (3 or more tests) using 1/____in² needle ______ lb  
9. **Average penetration resistance (#8 ÷ end area of needle) ______ lb/in²  
10. Optimum moisture from Dry Weight Curve (Curve No. ______) ______ %  
11. Moisture from Wet Weight Curve (Curve No. ______) or by drying ______ %  
12. Amount above #10 or below #11 optimum moisture (difference #10 & #11) ______ %  
13. Weight of sand + weight of density-cone apparatus ______ lb  
14. Weight of density-cone apparatus ______ lb  
15. Weight of sand in density-cone apparatus (#13 less #14) ______ lb  
16. Volume of density-cone apparatus (recorded on density-cone) ______ ft³  
17. Density of sand (#15 ÷ #16) ______ lb/ft³  
18. Weight of density-cone and remaining sand after cone is filled on leveled area ______ lb  
19. Weight of sand required to fill cone on leveled area (#13 less #18) ______ lb  
20. Weight of density-cone and remaining sand after filling auger hole & cone ______ lb  
21. Weight of sand in auger hole and cone (#18 less #20) ______ lb  
22. Weight of sand in auger hole (#21 less #19) ______ lb  
23. Volume of auger hole (#22 ÷ #17) ______ ft³  

Procedure when sample contains less than 1/10 total weight in stone retained on 3/4" or No. 4 sieve***  
24. Density of wet soil in fill (#3 ÷ #23) ______ lb/ft³  
25. Density of dry soil in fill ([#29 x #24] ÷ (#29 + #10)) ______ lb/ft³  
26. Max dry density (From Curve No. ______) ______ lb/ft³  
27. Compaction (#25 ÷ #26 x 100) ______ %  

Procedure when sample contains more than 1/10 total weight in stone retained on 3/4" or No. 4 sieve***  
28. Weight of Sample (#3) ______ lb  
29. Weight of stone removed from sample and retained on 3/4" or No. 4 sieve ______ lb  
30. Percent stone in sample (#29 ÷ #28 x 100) ______ %  
31. Weight of stone in one cubic foot of material (#24 x #30 ÷ 100) ______ lb  
32. Volume of stone in one cubic foot of material [#31 ÷ (Sp. Gr. * 62.4)] ______ ft³  
33. Volume of wet soil in one cubic foot of material (1.00 less #32) ______ ft³  
34. Weight of wet soil in one cubic foot of material (#24 less #31) ______ lb  
35. Density of wet soil (#34 ÷ #33) ______ lb/ft³  
36. Density of dry soil ([#35 x #10] ÷ (#11 + #10)) ______ lb/ft³  
37. Compaction with stone removed (#36 + #26 x 100) ______ %  
38. Moisture from zero air voids curve using (#25 or #36) ______ %  

*Average Specific Gravity Values: Limestone = 2.6; Gravel = 2.5; Sandstone and Sandy Shale = 2.2  
**Use this method only as a last resort.  
***Use No. 4 sieve for penetration method only.  

Does material tested meet specification requirements for: (write yes or no on each of following)  
Max. dry weight ______; Moisture ______; Compaction ______  

Does test check zero air voids curve (check which): Yes [ ] No [ ]  

Action taken by (check which): [ ] Inspector or [ ] Project Engineer  

If material tested does not meet specification requirements:  
[ ] Additional rolling ordered [ ] Aerating ordered [ ] Watering ordered [ ] Other  

Computed By [Blank] Checked By [Blank]  

DOT 12/4
Use for C-88 + C-89
**TEST NO. 1**

**Procedure for Determining Wet Weight Density**

- a. Weight of cylinder and contained wet soil
  
- b. Weight of cylinder
  
- c. Weight of contained wet soil (a less b)

- d. Density of wet soil in fill (c x 8.009)

**Procedure for Determining Percent Compaction**

- 4. Weight of 0.000943 m³ compacted wet soil + weight of container
- 5. Weight of 0.000943 m³ container
- 6. Weight of 0.000943 m³ compacted wet soil (#4 less #5)
- 7. Density of compacted wet soil (1060 x #6)

8. **Average penetration reading (3 or more tests) using _____ mm² needle**

9. **Average penetration resistance (#8 + end area of needle)**

10. Optimum moisture from Dry Density Curve (Curve No. _______) or by drying

11. Moisture from Wet Density Curve (Curve No. _______) or by drying

12. Amount above or below optimum moisture (difference #10 and #11)

25. Density of dry soil in fill \([(100 x d) \div (100 + #11)]\)

26. Max. Density (From Curve No. _______)

27. Compaction \(#25 \div #26 \times 100\)

**Use following spaces to record data for additional tests in nearby areas where soil and moisture conditions are the same by inspection, omitting Steps 4 through 12. If soil or moisture conditions are not the same for the other areas to be tested, use a new Form C-89-M instead of the following spaces.**

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<thead>
<tr>
<th>Comments</th>
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<td>Report No.</td>
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<tr>
<td>Dist. Rf. or Lt. of C.L. (m)</td>
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<tr>
<td>Approx. Elevation (m)</td>
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</tr>
<tr>
<td>a. * Wt. cyl. &amp; soil (g)</td>
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<td>b. * Wt. cyl. (g)</td>
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<tr>
<td>c. * Wt. soil (a less b) (g)</td>
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<tr>
<td>d. * Wet Density of soil (c x 8.009) (kg/m³)</td>
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<tr>
<td>25. * ([100 x d) \div (100 + #11)] (kg/m³)</td>
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<tr>
<td>27. * Compaction ($#25 \div #26$ x 100) (%)</td>
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<td>Specification Compaction Requirement</td>
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</table>

* Refers to corresponding steps for Test No. 1 above
** Use value for moisture and max. dry wt. per cubic meter obtained in Test No. 1
*** Use this method only as a last resort

Does material tested meet specification requirements for: (write yes or no on each of the following)

Max. dry density ______ ; Moisture ______ ; Compaction ______

Does test check zero air voids curve (check which): Yes ☐ No ☐

Action taken by (check which): ☐ Inspector or ☐ Project Engineer

If material tested does not meet specification requirements:

☐ Additional rolling ordered ☐ Aerating ordered ☐ Watering ordered ☐ Other ______

Computed By: ___________________________  Checked By: ___________________________
Use for C-88M + C-89M
**STATE OF OHIO**  
**DEPARTMENT OF TRANSPORTATION**  
**REPORT ON COMPACTION**  
*(Cylinder Density Method)*

Sample ID: __________ Personel ID: __________ Date Sampled: __ / __ / __

Type of Inspection: __________ Producer Code: __________ Contractor: __________

Material Code: __________ Test Results: __________

<table>
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</tr>
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</table>

Test of (check which):  
☐ Embankment  
☐ Subgrade  
☐ Base  
☐ Other  
Min. Compaction Req.: ___ %

From Sta __________ at __________ feet (rt. or lt.) of centerline, at approx. Elevation __________ ft

Read: *Manual of Procedures for Earthwork*

**TEST NO. 1**

**Procedure for Determining Wet Weight Density**

a. Weight of cylinder and contained wet soil ______ g

b. Weight of cylinder ______ g

c. Weight of contained wet soil (a less b) ______ g

d. Density of wet soil in fill (c ÷ 2) ______ lb/ft³

**Procedure for Determining Percent Compaction**

Note: Numbers of the following steps are the same as corresponding steps on Form C-88 (Water Added)

4. Weight of 1/30 ft³ compacted wet soil + weight of container ______ lb

5. Weight of 1/30 ft³ container ______ lb

6. Weight of 1/30 ft³ compacted wet soil (#4 less #5) ______ lb

7. Density of compacted wet soil (30 x #6) ______ lb/ft³

8. ***Average penetration reading (3 or more tests) using 1/___ in² needle ______ lb

9. ***Average penetration resistance (#8 + end area of needle) ______ lb/in²

10. Optimum moisture from Dry Density Curve (Curve No. __________) ______ %

11. Moisture from Wet Density Curve (Curve No. __________) or by drying ______ %

12. Amount above or below 0 optimum moisture (difference #10 and #11) ______ %

25. Density of dry soil in fill [(100 x d) ÷ (100 + #11)] ______ lb/ft³

26. Max. Density (From Curve No. __________) ______ lb/ft³

27. Compaction (#25 ÷ #26 x 100) ______ %

Use following spaces to record data for additional tests in nearby areas where soil and moisture conditions are the same by inspection, omitting Steps 4 through 12. If soil or moisture conditions are not the same for the other areas to be tested, use a new Form C-89 instead of the following spaces.

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<td>Approx. Elevation (ft)</td>
</tr>
<tr>
<td>a. * Wt. cyl. &amp; soil (g)</td>
</tr>
<tr>
<td>b. * Wt. cyl. (g)</td>
</tr>
<tr>
<td>c. * Wt. soil (a less b) (g)</td>
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<tr>
<td>d. * Wet Density of soil (c ÷ 2) (lb/ft³)</td>
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<tr>
<td>25. * [(100 x d) ÷ (100 + #11)] (lb/ft³)</td>
</tr>
<tr>
<td>27. * Compaction (#25 ÷ #26 * x 100) (%)</td>
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</table>

Specification Compaction Requirement

* Refers to corresponding steps for Test No. 1 above

** Use value for moisture and max. dry wt. per cubic foot obtained in Test No. 1

*** Use this method only as a last resort

Does material tested meet specification requirements for: (write yes or no on each of the following)

Max. dry density ______;  
Moisture ______;  
Compaction ______

Does test check zero air voids curve (check which):  
☐ Yes  
☐ No

Action taken by (check which):  
☐ Inspector  
☐ Project Engineer

If material tested does not meet specification requirements:

☐ Additional rolling ordered  
☐ Aerating ordered  
☐ Watering ordered  
☐ Other

Computed By: __________  
Checked By: __________

DOT 1221
Use for C-88 + C-89

* Computer re-drawn February 1996
### PROCEDURE FOR DETERMINING OPTIMUM MOISTURE AND MAXIMUM DRY WEIGHT

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<td>1. Weight of 0.000943 m³ compacted wet material and container</td>
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<td>2. Weight of 0.000943 m³ container</td>
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<tr>
<td>3. Weight of 0.000943 m³ compacted wet material (#1 less #2)</td>
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<td>4. Weight of 0.000943 m³ compacted dry material (by drying)</td>
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<td>5. Weight of water (#3 less #4)</td>
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<td>6. Moisture in percent (#5 ÷ #4 x 100)</td>
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<td>7. Density of compacted wet material (1060 x #3)</td>
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<td>8. Density of compacted dry material [(100 x #7) ÷ (100 + #6)]</td>
<td>kg/m³</td>
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<td>9. Optimum Moisture from Field Density Curve</td>
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<td>10. Maximum Dry Density from Field Density Curve</td>
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### TEST SECTION DATA

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<tr>
<td>Test Section compacted maximum wet density</td>
<td>kg/m³</td>
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</table>

### IN PLACE FIELD DENSITY DATA

|                | 13. | 14. | 15. | 16. | 17. | 18. | 19. | 20. | 21. | 22. | 23. | 24. | 25. | 26. | 27. | 28. | 29. | 30. | 31. | 32. | 33. | 34. |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Weight of sand + weight of density-cone apparatus | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of density-cone apparatus | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of sand in density-cone apparatus (#13 less #14) | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Volume of density-cone apparatus (recorded on density-cone) | m³ |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Density of sand (#15 ÷ #16) | kg/m³ |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of density-cone and remaining sand after cone is filled on leveled area | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of sand required to fill cone on leveled area (#13 less #18) | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of density-cone and remaining sand after filling auger hole and cone | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of sand in auger hole and cone (#18 less #20) | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of sand in auger hole (#21 less #19) | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Volume of auger hole (#22 ÷ #17) | m³ |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of wet material from auger hole + weight of container | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of container | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of wet material from auger hole (#24 less #25) | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of wet material taken for moisture sample | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of dry material taken for moisture sample (after drying) | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Weight of water (#27 less #28) | kg |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Moisture in percent (#29 ÷ #28 x 100) | % |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Density wet material in place (#26 ÷ #23) | kg/m³ |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Density dry material in place [(100 x #31) ÷ (100 + #30)] | kg/m³ |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 98% of Test Section Compacted Maximum Dry Density (98% x #11) | kg/m³ |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 98% of Test Section Compacted Maximum Wet Density (98% x #12) | kg/m³ |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

### NOTE:
Complete line 9 and 10 for all tests

Action taken by (check which): ☐ Inspector or ☐ Project Engineer

If material tested does not meet density requirements:
☐ Additional rolling ordered ☐ Aerating ordered ☐ Watering ordered ☐ Other

Computed By ___________________________ Checked By: ___________________________
Moisture - Percent of Dry Weight

Kilograms per cu. meter (wet weight)

Typical Moisture Density Curves Set "C"

Curves

<table>
<thead>
<tr>
<th>Curve</th>
<th>Max. dry wt.</th>
<th>Optimum Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2271</td>
<td>6.6</td>
</tr>
<tr>
<td>B</td>
<td>2228</td>
<td>7.2</td>
</tr>
<tr>
<td>C</td>
<td>2183</td>
<td>7.9</td>
</tr>
<tr>
<td>D</td>
<td>2148</td>
<td>8.5</td>
</tr>
<tr>
<td>E</td>
<td>2114</td>
<td>9.0</td>
</tr>
<tr>
<td>F</td>
<td>2071</td>
<td>9.7</td>
</tr>
<tr>
<td>G</td>
<td>2028</td>
<td>10.5</td>
</tr>
<tr>
<td>H</td>
<td>1990</td>
<td>11.2</td>
</tr>
<tr>
<td>I</td>
<td>1949</td>
<td>11.9</td>
</tr>
<tr>
<td>J</td>
<td>1911</td>
<td>12.7</td>
</tr>
<tr>
<td>K</td>
<td>1874</td>
<td>13.5</td>
</tr>
<tr>
<td>L</td>
<td>1836</td>
<td>14.6</td>
</tr>
<tr>
<td>M</td>
<td>1794</td>
<td>15.8</td>
</tr>
<tr>
<td>N</td>
<td>1756</td>
<td>16.9</td>
</tr>
<tr>
<td>O</td>
<td>1716</td>
<td>18.1</td>
</tr>
<tr>
<td>P</td>
<td>1677</td>
<td>18.2</td>
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<tr>
<td>Q</td>
<td>1640</td>
<td>20.3</td>
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<tr>
<td>R</td>
<td>1600</td>
<td>21.5</td>
</tr>
<tr>
<td>S</td>
<td>1560</td>
<td>22.7</td>
</tr>
<tr>
<td>T</td>
<td>1515</td>
<td>24.4</td>
</tr>
<tr>
<td>U</td>
<td>1475</td>
<td>25.8</td>
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<tr>
<td>V</td>
<td>1440</td>
<td>27.4</td>
</tr>
<tr>
<td>W</td>
<td>1402</td>
<td>29.5</td>
</tr>
<tr>
<td>X</td>
<td>1362</td>
<td>30.5</td>
</tr>
<tr>
<td>Y</td>
<td>1330</td>
<td>31.5</td>
</tr>
<tr>
<td>Z</td>
<td>1299</td>
<td>32.5</td>
</tr>
</tbody>
</table>

Originally Prepared by the Ohio State Highway Testing and Research Laboratory from results of tests on 10,000 Ohio soil samples

* Computer re-drawn February 1996

Use for C-90M + C-135B-M
PROCEDURE FOR DETERMINING OPTIMUM MOISTURE AND MAXIMUM DRY WEIGHT

Determination No. 1st 2nd 3rd 4th 5th
1. Weight of 1/30 ft³ compacted wet material and container lb
2. Weight of 1/30 ft³ container lb
3. Weight of 1/30 ft³ compacted wet material (#1 less #2) lb
4. Weight of 1/30 ft³ compacted dry material (by drying) lb
5. Weight of water (#3 less #4) lb
6. Moisture in percent (#5 ÷ #4 x 100) %
7. Density of compacted wet material (30 x #3) lb/ft³
8. Density of compacted dry material [(100 x #7) + (100 + #6)] lb/ft³
9. Optimum Moisture from Field Density Curve %
10. Maximum Dry Density from Field Density Curve lb/ft³

TEST SECTION DATA

11. Test Section compacted maximum dry density lb/ft³
12. Test Section compacted maximum wet density lb/ft³

IN PLACE FIELD DENSITY DATA

13. Weight of sand + weight of density-cone apparatus lb
14. Weight of density-cone apparatus lb
15. Weight of sand in density-cone apparatus (#13 less #14) lb
16. Volume of density-cone apparatus (recorded on density-cone) ft³
17. Density of sand (#15 ÷ #16) lb/ft³
18. Weight of density-cone and remaining sand after cone is filled on leveled area lb
19. Weight of sand required to fill cone on leveled area (#13 less #18) lb
20. Weight of density-cone and remaining sand after filling auger hole and cone lb
21. Weight of sand in auger hole (#18 less #20) lb
22. Weight of sand in auger hole (#21 less #19) lb
23. Volume of auger hole (#22 ÷ #17) ft³
24. Weight of wet material from auger hole + weight of container lb
25. Weight of container lb
26. Weight of wet material from auger hole (#24 less #25) lb
27. Weight of wet material taken for moisture sample lb
28. Weight of dry material taken for moisture sample (after drying) lb
29. Weight of water (#27 less #28) lb
30. Moisture in percent (#29 ÷ #28 x 100) %
31. Density wet material in place (#26 ÷ #23) lb/ft³
32. Density dry material in place [(100 x #31) + (100 + #30)] lb/ft³
33. 98% of Test Section Compacted Maximum Dry Density (98% x #11) lb/ft³
34. 98% of Test Section Compacted Maximum Wet Density (98% x #12) lb/ft³

NOTE: Complete line 9 and 10 for all tests

Action taken by (check which): ☐ Inspector or ☐ Project Engineer
If material tested does not meet density requirements:
☐ Additional rolling ordered ☐ Aerating ordered ☐ Watering ordered ☐ Other
Computed By: ______________________ Checked By: ______________________
DOT-1238
Moisture - Percent of Dry Weight

Typical Moisture Density Curves Set "C"

Originally Prepared by the Ohio State Highway Testing and Research Laboratory from results of tests on 10,000 Ohio soil samples*

<table>
<thead>
<tr>
<th>Curve</th>
<th>Max. dry wt. lbs/cu.ft</th>
<th>Optimum Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>141.8</td>
<td>6.6</td>
</tr>
<tr>
<td>B</td>
<td>139.1</td>
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<tr>
<td>C</td>
<td>136.3</td>
<td>7.9</td>
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<tr>
<td>D</td>
<td>134.1</td>
<td>8.5</td>
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<tr>
<td>E</td>
<td>132.0</td>
<td>9.0</td>
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<tr>
<td>F</td>
<td>129.3</td>
<td>9.7</td>
</tr>
<tr>
<td>G</td>
<td>126.6</td>
<td>10.5</td>
</tr>
<tr>
<td>H</td>
<td>124.2</td>
<td>11.2</td>
</tr>
<tr>
<td>I</td>
<td>121.7</td>
<td>11.9</td>
</tr>
<tr>
<td>J</td>
<td>119.3</td>
<td>12.7</td>
</tr>
<tr>
<td>K</td>
<td>117.0</td>
<td>13.5</td>
</tr>
<tr>
<td>L</td>
<td>114.6</td>
<td>14.6</td>
</tr>
<tr>
<td>M</td>
<td>112.0</td>
<td>15.8</td>
</tr>
<tr>
<td>N</td>
<td>109.6</td>
<td>16.9</td>
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<tr>
<td>O</td>
<td>107.1</td>
<td>18.1</td>
</tr>
<tr>
<td>P</td>
<td>104.7</td>
<td>19.2</td>
</tr>
<tr>
<td>Q</td>
<td>102.4</td>
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<td>V</td>
<td>89.9</td>
<td>27.4</td>
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<tr>
<td>W</td>
<td>87.5</td>
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<td>31.5</td>
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<tr>
<td>Z</td>
<td>81.1</td>
<td>32.5</td>
</tr>
</tbody>
</table>

* Computer re-drawn February 1996

Use for C-90 + C-135B
<table>
<thead>
<tr>
<th>Test of (check which):</th>
<th>%</th>
<th>Min. Compaction Req.:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embankment</td>
<td>□</td>
<td></td>
</tr>
<tr>
<td>Subgrade</td>
<td>□</td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>□</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>□</td>
<td></td>
</tr>
</tbody>
</table>

**Test Results:**

<table>
<thead>
<tr>
<th>Project/P.O.</th>
<th>P.O. Ind.</th>
<th>Item Code</th>
<th>Ref. Number</th>
<th>Item Code</th>
<th>Ref. Number</th>
</tr>
</thead>
</table>

**From Sta.** __________ at _______ meters (rt. or lt.) of centerline to

<table>
<thead>
<tr>
<th>Station of test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Station of test</td>
</tr>
<tr>
<td>2. Distance right or left of centerline if different than above _______ (m)</td>
</tr>
<tr>
<td>3. Approximate Elevation if different than above _______ (m)</td>
</tr>
</tbody>
</table>

**Procedure for Determining Dry and Wet Density**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>Standard Count for Density</td>
</tr>
<tr>
<td>5.</td>
<td>Wet Density of soil from gauge _______ (kg/m³)</td>
</tr>
<tr>
<td>6.</td>
<td>Dry Density of soil from gauge _______ (kg/m³)</td>
</tr>
</tbody>
</table>

**Procedure for Determining Moisture Content**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>Standard Count for moisture</td>
</tr>
<tr>
<td>8.</td>
<td>Moisture content of soil from gauge _______ (%)</td>
</tr>
<tr>
<td>9.</td>
<td>Check for moisture content [(#5 ÷ #6 x 100)-100] _______ (%)</td>
</tr>
</tbody>
</table>

**Take sample (about 4.5 kg) of material from area tested for density.**

**Procedure when sample contains less than 1/10 total weight in stone retained on 19.0 mm or 4.75 mm sieve**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.</td>
<td>Weight of 0.000943 m³ compacted wet soil + weight of container (kg)</td>
</tr>
<tr>
<td>11.</td>
<td>Weight of 0.000943 m³ container (kg)</td>
</tr>
<tr>
<td>12.</td>
<td>Weight of 0.000943 m³ compacted wet soil (#10 - #11) (kg)</td>
</tr>
<tr>
<td>13.</td>
<td>Density of compacted wet soil (1060 x #12) (kg/m³)</td>
</tr>
<tr>
<td>14.</td>
<td>Optimum moisture from dry density curve, Curve No. (#13) (%)</td>
</tr>
<tr>
<td>15.</td>
<td>Maximum Dry Density Curve No. (#14) (kg/m³)</td>
</tr>
<tr>
<td>16.</td>
<td>Amount above □ or below □ optimum moisture (#14 - #8) (%)</td>
</tr>
<tr>
<td>17.</td>
<td>Compaction [(#6 + #15) x 100] (%)</td>
</tr>
<tr>
<td>17a.</td>
<td>Moisture from the zero air voids curve using line 6</td>
</tr>
</tbody>
</table>

**Does material tested meet Specification requirements? Yes-□ No-□**

**A** Roiling ordered; **B** Aerating ordered; **C** Watering ordered

**Date Tested**

**Computed By**

**Checked By**

---

In percent of Dry Density. **Lines 8 & 9 should be the same**

**Refer to C-85-M, lines 28 - 38 when soil sample contains more than 1/10 total weight in stone retained on 19.0 mm or 4.75 mm sieve; Use No. 4 sieve for penetration method only.**
Use for C-90M + C-135B-M

* Computer re-drawn February 1996
**STATE OF OHIO**
**DEPARTMENT OF TRANSPORTATION**
**NUCLEAR GAUGE COMPACTATION FORM**

Sample ID:  
Personnel ID:  
Date Sampled:  
Type of Inspection:  
Producer Code:  
Contractor:  
Material Code:  
Test Results:  

<table>
<thead>
<tr>
<th>Project/P.O.</th>
<th>P.O. Ind.</th>
<th>Item Code</th>
<th>Ref. Number</th>
<th>Item Code</th>
<th>Ref. Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test of (check which):  
- Embankment  
- Subgrade  
- Base  
- Other  
Min. Compaction Req.:  

Test of (check which):  
- Limestone  
- Gravel  
- Slag  
- Sandstone  
- Granulated Slag  
- Other  

From Sta.  at  feet (rt. or lt.) of centerline to Sta.  at  feet (rt. or lt.) of centerline, at approx. Elevation  ft  
See Report No.  

(choose which):  
- Wet  
- Dry  

Maximum Density from Test Section  lb/ft³  
Optimum Moisture  %  

98% of Max. Density  lb/ft³  

Check Method used:  
- Direct Transmission  
- Backscatter  
- Probe Depth  inches  

| 1. | Station of test |
| 2. | Distance right or left of centerline if different than above (ft) |
| 3. | Approximate Elevation if different than above (ft) |

### Procedure for Determining Dry and Wet Density

4. Standard Count for Density  
5. Wet Density of soil from gauge (lb/ft³)  
6. Dry Density of soil from gauge (lb/ft³)  

### Procedure for Determining Moisture Content

7. Standard Count for moisture  
8. Moisture content of soil from gauge * (%)  
9. Check for moisture content [(#5 + #6 x 100) - 100] (%)**  

Take sample (about 10 lb) of material from area tested for density.  

**Procedure when sample contains less than 1/10 total weight in stone retained on 3/4" or No. 4 sieve**

10. Weight of 1/30 ft³ compacted wet soil + weight of container (lb)  
11. Weight of 1/30 ft³ container (lb)  
12. Weight of 1/30 ft³ compacted wet soil (#10 - #11) (lb)  
13. Density of compacted wet soil (30 x #12) (lb/ft³)  
14. Optimum moisture from dry density curve Curve No. (%)  
15. Maximum Dry Density Curve No. (%)  
16. Amount above □ or below □ optimum moisture (#14 - #8) (%)  
17a. Moisture from the zero air voids curve using line 6 (%)  
18. Does material tested meet Specification requirements? Yes □ No □  
19. "A" Rollin ordered; "B" Aerating ordered; "C" Watering ordered  
20. Date Tested  

* In percent of Dry Density.  
** Lines 8 & 9 should be the same.  
** Refer to C-88, lines 28 through 38 when soil sample contains more than 1/10 total weight in stone retained on 3/4" or No. 4 sieve; Use No. 4 sieve for penetration method only.

Computed By  
Checked By
Moisture - Percent of Dry Weight

Typical Moisture Density Curves Set "C"

Originally Prepared by the Ohio State Highway Testing and Research Laboratory from results of tests on 10,000 Ohio soil samples

* Computer re-drawn February 1996

Use for C-90 + C-135B & C-171-E
STATE OF OHIO
DEPARTMENT OF TRANSPORTATION
NUCLEAR GAUGE REPORT ON COMPACTION WITH AN AGGREGATE CORRECTION

Sample ID: __________________________ Personnel ID: __________________________ Date Sampled: ___/___/___

Type of Inspection: __________________________ Producer Code: __________________________ Contractor: __________________________

Material Code: __________________________ Test Results: __________________________

<table>
<thead>
<tr>
<th>Project/P.O.</th>
<th>P.O. Ind.</th>
<th>Item Code</th>
<th>Ref. Number</th>
<th>Item Code</th>
<th>Ref. Number</th>
</tr>
</thead>
</table>

Test of (check which): ☐ Embankment ☐ Subgrade ☐ Base ☐ Other __________________________ Min. Compaction Req.: ____

From Sta _______________ + _______________ at _______________ feet _______________ (rt. or lt.) of centerline, at approx. Elevation _______________ ft

Read: "Manual of Procedures for Earthwork"

I. Nuclear Gauge Readings

1. Standard Count for Density
2. Standard Count for Moisture
3. Wet Density of the Soil From the Gauge
4. Dry Density of the Soil From the Gauge
5. Percent Moisture from Gauge

II. Remove the Soil from Under Gauge and Sieve the Soil Through a 3/4" Sieve

6. Weight of wet soil (& stone, if any) from hole + weight of pan
7. Weight of Pan or Container
8. Weight of wet soil (& stone, if any) from under the nuclear gauge (#6 less #7)
9. Weight of stone & Sieve or Pan
10. Percent stone in sample (#9b ÷ #8 x 100)

III. Proctor Test Using the Soil Passing the 3/4" Sieve

11. Weight of 1/30 ft³ compacted wet soil + weight of container
12. Weight of 1/30 ft³ container
13. Weight of 1/30 ft³ compacted wet soil (#11 less #12)
14. Density of compacted wet soil (30 X #13)

IV. Pick The Correct Curve From the Ohio Typical Density Curves Using #14 and # (5 or 16)

15. Optimum moisture from Dry Weight Curve (Curve No. ___)
16. Moisture from Line 5 or Corrected moisture by Drying if Required
17. Amount above ☐ or below ☐ optimum moisture (difference #15 & #16)
18. Maximum Dry Density (From Curve No. ___)

V. Compaction Calculation Procedure When Line 10 is less than 10%

19. Compaction (#4 ÷ #18 x 100)

VI. Compaction Calculation When Line 10 is greater than 10% and less than 25%**

20. Weight of stone in one cubic foot of material (#3 x #10 ÷ 100)
21. Volume of stone in one cubic foot of material [#20 ÷ (Sp. Gr. * 62.4)]
22. Volume of wet soil in one cubic foot of material (1.00 less #21)
23. Weight of wet soil in one cubic foot of material (#3 less #20)
24. Corrected Wet Density of the Soil in the Fill (#23 ÷ #22)
25. Corrected Dry Density of the Soil In the Fill (#24 x 100) ÷ (#5 + 100)
26. Compaction with stone removed (#25 ÷ #18 x 100)
27. Moisture from zero air voids curve using (#4 or #25)

* Average Specific Gravity Values: Limestone = 2.6; Gravel = 2.5; Sandstone and Sandy Shale = 2.2

** If line 10 is greater than 25%, make a Granular Moisture Density Curve and use the Test Section Method.

Does material tested meet specification requirements for: (write yes or no on each of following)

Max. dry weight: ☐ Yes ☐ No
Moisture: ☐ Yes ☐ No
Compaction: ☐ Yes ☐ No

Does test check zero air voids curve (check which): ☐ Yes ☐ No

Action taken by (check which): ☐ Inspector or ☐ Project Engineer

If material tested does not meet specification requirements:
☐ Additional rolling ordered ☐ Aerating ordered ☐ Watering ordered ☐ Other __________________________

Computed By __________________________ Checked By __________________________

DOT-1634 -file:w:forms/mycopy:c171e
Use for C-90 + C-135B & C-171-E

* Computer re-drawn February 1996
STATE OF OHIO  
DEPARTMENT OF TRANSPORTATION  
ITEM 307 NON STABILIZED DRAINAGE BASE COMPACTION FORM

Sample ID: ___________________________ Personnel ID: ___________________________ Date Sampled ___/___/______
Type of Inspection: ___________________ Producer Code: ___________________ Contractor: ___________________
Code: ___________________ Test Results: ___________________

1) MOISTURE TESTING

SSD Moisture ____% Required Moisture Content (M %) ________ Add Water ___ Yes ___ No ___ Location ________

Note: Required Specification Moisture: SSD + 3 % @ Pugmill and SSD + 1½ @ Compaction
Take random samples to ensure the moisture is maintained at the pugmill and during compaction.

2) TEST SECTION TESTS FOR DRY DENSITY AND MOISTURE IN CONTROL STRIP (@ 400 s.y.)

<table>
<thead>
<tr>
<th>Number of Passes to Seat Material</th>
<th>M% = Actual Moisture Content, Avg = Average Dry Density at Three Random Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>Test 2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
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<tr>
<td>Avg</td>
<td>Avg</td>
</tr>
<tr>
<td>M%</td>
<td>M%</td>
</tr>
</tbody>
</table>

Total Passes, Seating Passes plus Testing Section Passes, to Obtain Maximum Dry Density ________ (Minimum # for Production Compaction)

Note: One Coverage Is Two Passes  Minimum Passes: 2-Type NJ, 4-Type IA, 6-Type CE  Circle the Maximum Dry Density

3) AVERAGE DRY DENSITY FROM CONTROL STRIP

1 _______ 2 _______ 3 _______ 4 _______ 5 _______
6 _______ 7 _______ 8 _______ 9 _______ 10 _______

Average Dry Density ________ 95% of Control Strip ________

4) PRODUCTION DRY DENSITY COMPACTION TESTS (@ 5000 Square Yard Lots)

Lot# _______ STATION _______ to STATION _______ Number of Passes Actually Used _______
1 _______ 2 _______ 3 _______ 4 _______ 5 _______ Average _______ Pass ___ Fail ___

Lot# _______ STATION _______ to STATION _______ Number of Passes Actually Used _______
1 _______ 2 _______ 3 _______ 4 _______ 5 _______ Average _______ Pass ___ Fail ___

Lot# _______ STATION _______ to STATION _______ Number of Passes Actually Used _______
1 _______ 2 _______ 3 _______ 4 _______ 5 _______ Average _______ Pass ___ Fail ___

Computed By ___________________________ Checked By ___________________________

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