Compaction Testing
Module 9
Compaction Specifications

General

- MAMD Method required
- Compaction Testing required for lifts 2” and greater.
- Core Correlations
  - A Boilerplate Specification and Bid Item have been developed and will be in use on most larger paving projects.
  - Other Projects - optional for lifts 2” or thicker
- CDT Required
- Calibrated Nuclear Gauge Required

Compaction Specifications

Areas not subject to compaction measurement

00745.49(d) Other Areas – Compaction to a specified density will not be required on temporary surfacing, guardrail flares, mailbox turnouts, road approaches, pavement repair, and areas less than 8 feet wide or limited length, regardless of thickness. Compact these surfaces according to 00749.45.
Compaction Specifications

00749.45 Compacting Asphalt Concrete – Compact asphalt concrete according to the following or as directed:

- Compaction to a specified density will not be required, regardless of thickness. Perform breakdown and intermediate rolling until the entire surface has been compacted with at least four coverages by the rollers. Perform additional coverages, as directed, to obtain finish rolling of the ACP.

- Along curbs and walls, on walks, irregular areas, and other areas not practically accessible to rollers conforming to 00744.24 or 00745.24, compact the mixture with small, self-propelled rollers, mechanical tampers, or hand rollers. On depressed areas a trench roller may be used, or cleated compression strips may be used under the roller to transmit compression to the depressed area.

Compaction Specifications Testing Requirements

00745.49(b-2) Random Testing – Determine the density of each sublot by averaging five QC tests performed at random locations with the nuclear gauge operated in the backscatter mode. Lots and sublots shall correspond with those defined in 00745.02. In addition, perform at least one density test each day of production. The additional testing may be waived by the Engineer.*

a. Testing – After completion of the finish rolling, test according to AASHTO T 355. Do not locate the center of a density test less than 1 foot from the panel edge. Complete density testing before traffic is allowed on the new mat.
Compaction Specifications
Density Requirements

00745.49(b-3) When this method is used, compact the ACP to at least the percent of the MAMD applicable for the mix type and lift as follows:

<table>
<thead>
<tr>
<th>Course of Construction</th>
<th>ACP</th>
</tr>
</thead>
<tbody>
<tr>
<td>First ACP lift less than 3 inches placed on aggregate base</td>
<td>91.0 *</td>
</tr>
<tr>
<td>All other</td>
<td>92.0</td>
</tr>
</tbody>
</table>

*If any part of the width of a lift at a station requires 91.0%, then the entire width of that lift at that station shall be 91.0%*

Control Strips

A tool for:
- Establishing and evaluating a roller pattern
- Determining the maximum density that can be achieved with conditions on the project
- Ensuring consistent density across the mat
**Compaction Specifications**

**Control Strips**

00745.49(b-1) Construct a control strip at the beginning of work on each JMF on the project according to ODOT TM 306. The purpose of the control strip is to determine the maximum density that can be achieved for the JMF, paving conditions, and equipment on the project. Additional control strips are necessary when there is a change in compaction equipment or when JMF targets are adjusted according to 00745.16(b-1-a). The Engineer may waive the control strip for irregular areas or areas too small to establish a reasonable roller pattern.

Stop paving if three consecutive control strips fail to achieve the specified density. Take all actions necessary to resolve compaction problems. Do not resume paving until allowed by the Engineer.
Control Strip

NOTE: IF A IS LESS THAN C, MOVE AHEAD, CHANGE ROLLING PATTERN AND START OVER.

<table>
<thead>
<tr>
<th>STATION</th>
<th>1.0 Ft from LEFT</th>
<th>MIDPOINT LEFT</th>
<th>CENTER</th>
<th>MIDPOINT RIGHT</th>
<th>1.0 Ft from LEFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>152.3</td>
<td>156.5</td>
<td>155.9</td>
<td>153.2</td>
<td>154.2</td>
</tr>
<tr>
<td>2</td>
<td>153.2</td>
<td>155.4</td>
<td>157.8</td>
<td>154.4</td>
<td>153.9</td>
</tr>
<tr>
<td>3</td>
<td>152.8</td>
<td>156.9</td>
<td>156.9</td>
<td>153.8</td>
<td>154.1</td>
</tr>
<tr>
<td>4</td>
<td>148</td>
<td>151.2</td>
<td>152.1</td>
<td>149</td>
<td>149.3</td>
</tr>
</tbody>
</table>

Cores (physical measurement of density)

Nuclear gauges (estimate of density using radioactive particle techniques)

Re: Compaction

Two Primary Measurement Methods

- Cores (physical measurement of density)
- Nuclear gauges (estimate of density using radioactive particle techniques)
Nuclear Gauge Precision

-1.8 pcf  -1.2 pcf  -0.6 pcf  Ave  0.6 pcf  1.2 pcf  1.8 pcf
Nuclear Gauge Precision
100 tests at One Location

66 out of 100
95 out of 100

138.2 pcf (90.8%)
138.8 pcf (91.2%)
139.4 pcf (91.6%)
140.0 pcf (92%)
140.6 pcf (92.4%)
141.2 pcf (92.8%)
141.8 pcf (93.2%)

Compaction Test Procedure
AASHTO T 355

Have QCCS or QA representative on-site at start-up to verify that proper procedures are being followed by the Contractor’s CDT. Call them back in if a problem is suspected.
Things to Look For

- Does the random location match what the technician submitted?
- Does the test location violate any of the distance rules (30'-radioactivity, 10'-large objects, 2'-vertical edge, 1'-pavement edge)?
- Was the test taken after the finish roller had completed the required passes?
- Was the test area sanded and excess sand removed?

Things to Look For

- Was the footprint of the gauge marked and the gauge seated correctly?
- Was the gauge rotated about the center during the test?
- Is the technician using the correct MAMD value?
- Is the correct percentage compaction being obtained 91.0% or 92.0%?
Things to Look For

- Are any tests exceeding 95% of the MAMD value? Watch for high density trends appearing on the roadway.
- The inspector should be notified of compaction results and any problems identified by the technician.

Core Correlations

- Purpose: To adjust gauge readings to what the density would be if each test location was cored (cores being the actual density)
- Perform:
  - When required by spec
  - When gauge readings are questionable
  - When QC and QA results are substantially different
- A new correlation is required:
  - For each new lift
  - For each JMF
Core Correlations
Procedure

- Select 10 random locations (ok to use control strip or subplot test locations)
- Test each location with both QC and QA gauges per ODOT TM 327
- Drill a core at each location
- Test the cores for density
- Develop correlation factor to apply to nuke gauge readings
Example Problem

- Sublot Compaction Report
# Nuclear Compaction Test Report for ACP

**Project Name:** ACP 17-MD00 117

**Date:** January 2019

<table>
<thead>
<tr>
<th>Compaction Type</th>
<th>Description</th>
<th>Project Manager</th>
<th>Site Manager</th>
<th>Contract Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5&quot; Edlund Roller</td>
<td>Troxler 3440-32B25</td>
<td>17-MD00</td>
<td>311 - 321</td>
<td>320</td>
</tr>
</tbody>
</table>

**Roller Type and Description:**

- **Breakdown:** Cat-CB64 DDV
- **Intermediate:** Cat-CB64 DDV
- **Finish:** Cat-CB64 DDV

**Test Number:**

- 1-19-6
- 1-19-7
- 1-19-8
- 1-19-9
- 1-19-10

**Date of Test:**

- 10/2/2017
- 10/2/2017
- 10/2/2017
- 10/2/2017
- 10/2/2017

**Asphalt Depth:**

- 8.7
- 3.9
- 10.6
- 9.2
- 7.9

**Density (lb/ft³):**

- 142.4
- 139.9
- 143.2
- 141.6
- 140.1

**Correlation:**

- 144.1
- 140.9

**Target Density (lb/ft³):**

- 515.2
- 515.2
- 515.2
- 515.2
- 515.2

**Remarks:**

- 95.3%
- 93.2%

**From Station:** 550+00

**To Station:** 92+00

**Percentage of Material Incorporated:**

- 93.0%
Training Objectives

- Understanding Stratified Random Sampling
- Annex Terminology
- Formulas to Compute “Yield”
- Process for generating Random Numbers
- Applying Random Numbers to tonnage increments
- Determining Test Site Distance
- Managing Partial Sublots
- Managing Irregular Areas

Random Sampling Concepts

LOT LOT DIVIDED INTO SUBLOTS

STRAIGHT STRATIFIED

ACP density sites based on stratified method
Annex Terminology

MAMD – Moving Average Maximum Density

- Expressed in lbs / ft³
- Used to compute in-place density
- Determined according to ODOT TM 305 in conjunction with AASHTO T 209
- Determined at the beginning of the shift
- Based on a running average of 5 tests

Panel Thickness & Width

- Panel thickness or depth is taken from project typical sections
- Panel width taken from project typical section
- Width is adjusted in the field based on staging, overlap requirements; if applicable and striping offsets
Annex Terminology

Average Volume per Ton

- A value in ft³ / ton that is adjusted for the actual unit weight of the ACP and the average in-place percent compaction
- MAMD and % Compaction are needed
  - MAMD 150.9 lbs / ft³
  - % Compaction 91.0

\[
Average \ Volume \ per \ Ton = \frac{2000\ lbs/ton}{150.9\ lbs/ft^3 \times 0.91} = 14.57\ ft^3/ton
\]

Annex Terminology

Cross-Sectional Area

- The area in ft² based on the panels width and depth.
- Dimensions expressed in feet
- Depth 2" / 12" / ft = 0.167 ft
- Width 16 ft

\[
Cross - Sectional \ Area = 0.167\ ft \times 16\ ft = 2.67\ ft^2
\]
Annex Terminology

Yield

- Expressed in ft / ton, based on the average volume per ton and cross-sectional area
- Provides a factor used to determine paving distance

\[
Yield = \frac{14.57 \text{ ft}^2}{2.67 \text{ ft}^2 / \text{ ton}} = 5.46 \text{ ft} / \text{ ton}
\]

Lot and Sublot

- A lot represents the entire material as a whole.
- A sublot breaks the lot into 1000 ton increments.
- Each sublot is then stratified into 200 ton segments.

*Note: Partial sublots, less than 1000 tons, must be stratified to ensure 5 density locations are established.*
**Procedure**

**Step 1:** Compute the Average Volume per Ton based on the following inputs:

- MAMD = 151.9 lbs/ft$^3$
- Density Requirement = 92.0% (0.92) or average density determined in the field. (Express % Compaction in a decimal form).

\[
\text{Average Volume} = \frac{2000 \text{ lbs/ton}}{151.9 \text{ lbs/ft}^3 \times 0.92}
\]

**Procedure**

**Step 2:** Calculate the Cross-Sectional Area. The following inputs are required and expressed in feet.

- Panel Thickness = 2" (2"/12") is (0.167 ft.)
- Panel Width = 16 ft.
Procedure

Step 3: Calculate the Yield in feet per ton by dividing the average volume by the cross-sectional area.

\[
\text{Average Volume per Ton} = 14.31 \text{ ft}^3 / \text{ton}
\]

\[
\text{Cross - Sectional Area} = (0.167 \text{ ft} \times 16 \text{ ft} = 2.67 \text{ ft}^2)
\]

\[
Yield = \frac{14.31 \text{ ft}^3 / \text{ton}}{2.67 \text{ ft}^2}
\]

Procedure

Step 4: Generate 5 random numbers. First 3 for longitudinal and remaining 2 for transverse or offset distance.

Convert the random number to a decimal. Take first 3 and multiply by 0.001 and remaining 2 and multiply by 0.01.

<table>
<thead>
<tr>
<th>Longitudinal</th>
<th>Transverse / Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 16897</td>
<td>168 x 0.001 = 0.168</td>
</tr>
<tr>
<td>2. 16066</td>
<td>160 x 0.001 = 0.160</td>
</tr>
<tr>
<td>3. 85075</td>
<td>850 x 0.001 = 0.850</td>
</tr>
<tr>
<td>4. 92639</td>
<td>926 x 0.001 = 0.926</td>
</tr>
<tr>
<td>5. 35721</td>
<td>357 x 0.001 = 0.357</td>
</tr>
</tbody>
</table>
Procedure

Step 5: Take the 1000 ton sublot and divide by 5 to create segments, each representing 200 tons.

Taking the random numbers generated in Step 4, apply to the 200 ton segmented areas to compute a random tonnage between each increment.

1st Segment Longitudinal Tonnage = 0.168 x 200 = 34 tons.

2nd Segment Longitudinal Tonnage = 0.160 x 200 = 32 tons.

3rd Segment Longitudinal Tonnage = 0.850 x 200 = 170 tons.

4th Segment Longitudinal Tonnage = 0.926 x 200 = 185 tons.

5th Segment Longitudinal Tonnage = 0.357 x 200 = 71 tons.
Procedure

- The random tonnages computed in Step 5 only have relationship to the individual segments.
- To ensure the 200 ton stratification is maintained, each random tonnage within the 200 ton segments must be added to the next 200 ton segment.
- 1st segment, 0-200 tons has a random location of 34 tons, so this segment's random tonnage remains the same. 0 + 34 = 34 tons.
- 2nd segment, 200-400 tons has a random location of 32 tons, so this segment's random tonnage would be 32 + 200 = 232 tons.
- Process would continue until all 5 sites are located.

Procedure

Step 6: Compute the distance associated to the random tonnage using the yield factor computed in Step 3.

The site can also be determined using the actual tonnage placed based on delivery invoices.

1st location = 34 tons + 0 tons = 34 tons.
Site distance = 34 x 5.36'/ton = 182'

2nd location = 32 tons + 200 tons = 232 tons.
Site distance = 232 x 5.36'/ton = 1244'

3rd location = 170 + 400 tons = 570 tons
Site distance = 570 x 5.36'/ton = 3055'

4th location = 185 tons + 600 tons = 785 tons
Site distance = 785 x 5.36'/ton = 4208'

5th location = 71 tons + 800 tons = 871 tons
Site distance = 871 x 5.36'/ton = 4669'
Procedure

A check of the layout can be determined as follow:

- 1000 tons x 5.36’ / ton = 5360’
  (total distance based on 1000 tons)
- 1000 tons – 871 (5th random) = 129 tons
- 129 tons x 5.36’ / ton = 691’
- 4669’ (5th site distance) + 691’ = 5360’
  (distance matches the overall tonnage based on 1000 tons)

Determining Distance

Distance can be determined from the beginning of the 1000 ton segment or measured from the last test site.

**Example:** Random site #1 had a distance of 182’. If the distance to site #2 was 1244’, than simply compute the difference between the two sites.

- 1244’ - 182’ = 1062’.
- Now measure 1062’ from site #1 to identify site #2’s location.
- Repeat this process for the remaining test sites.
**Procedure**

**Step 7:** Determine the transverse or offset distance at each longitudinal random location. Site location cannot be within 1’ of either edge of the panel. Offset Distance from Rt. Edge = ((Panel Width – 2) X random number) + 1

<table>
<thead>
<tr>
<th>Right Edge</th>
<th>Paving Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 T</td>
<td>Site 18'</td>
</tr>
<tr>
<td>200 T</td>
<td>Site 12'</td>
</tr>
<tr>
<td>400 T</td>
<td>Site 30'</td>
</tr>
<tr>
<td>600 T</td>
<td>Site 42'</td>
</tr>
<tr>
<td>800 T</td>
<td>Site 46'</td>
</tr>
<tr>
<td>1000 T</td>
<td>Site 46'</td>
</tr>
</tbody>
</table>

1\(^{st}\) location = ((16’ -2) x 0.97) + 1 = 14.6’

2\(^{nd}\) location = ((16’ -2) x 0.66) + 1 = 10.2’

3\(^{rd}\) location = ((16’ -2) x 0.75) + 1 = 11.5’

4\(^{th}\) location = ((16’ -2) x 0.39) + 1 = 6.5’

5\(^{th}\) location = ((16’ -2) x 0.21) + 1 = 3.9’

- If the dimensions of the panel change during placement, then the yield factor should be adjusted to accurately determine the site distance.

- Once the site is identified, clearly mark the center point of the test location with lumber crayon or keel.

**Site Locations must be marked after finish rolling, ASAP, to prevent Construction delays.**
Site Location Adjustments

- On a daily basis there may be some form of carry-over paving, which causes a sublot to be partially completed.
- The remaining random numbers are still valid, but the tonnage association will change.
- Also, the MAMD and in-place compaction will tend to change on a daily basis.
- The inspector must be mindful of these changes and make appropriate adjustments to accurately compute test site locations.

MAMD (Moving Average Maximum Density)

- MAMD will change to a certain degree daily and change the yield calculation.
- Change is due to fluctuations in the ACP during production based on:
  - Gradation
  - Oil content
  - Mix adjustments
In-Place Compaction

- The ft/ton factor can be impacted by changes in compactive effort.
- 92.0 was the initial starting point for the calculation, but doesn’t take into account actual density on the grade.
- The average compaction measured by the CDT should be used and like MAMD will change daily.

Actual Yield versus Theoretical Yield

- The greatest impact to the yield calculation and its use to determine random locations are changes in the panels geometry.
- Continuous monitoring of the panels actual dimensions is critical to ensure the theoretical yield is maintained.
- Fluctuations in depth or width can cause the random location to be in error, if adjustments aren’t made.
- The inspector should check the actual compacted panel and ensure the depth and width are correct and match the inputs for the theoretical yield.
Actual Yield versus Theoretical Yield

- Checking the actual compacted panels dimensions, also ensures the contractor is constructing the section according to the plans.
- In conjunction with physical measurements, the inspector should check actual yield based on placed material.
- Every 10 trucks of placed material, or approximately 200 tons, is a good interval to check and works well with the 200 ton segment areas used for random locations.
- Have ticket taker mark 200 and 1000 ton increments during paving for a check reference of yield, if possible.

Managing a Partial Sublot

- There will be some carry-over from one paving day to the next, which might create the necessity to break a subplot.
- In turn, the MAMD and percent compaction will change for the next day and the panel dimensions might change, which will impact the yield calculations.
- This change needs to be tied to the previous site locations, so the 200 tons segmented areas stay consistent and the distance stays as accurate as possible.
Example of a Partial Sublot

- Day 1, a total of 590 tons of ACP was placed and 3 random sites were identified.
- This is short 410 tons to complete the 1000 ton sublot, so two random locations remain. **Note:** 10 tons is included with last random site number 3 representing tonnage segment 400 to 600 tons, which needs to be accounted for in the next random determinations.
- Paving dimensions are same as the day before, 2” depth and 16’ panel width.
- The last two series of random numbers from the day before can be utilized to complete the sublot.

Example of a Partial Sublot

- A new MAMD value of 152.9 lbs/ft³ was provided by the CAT-1.
- The average compaction was 93.4% measured by the contractor’s CDT.
- Compute yield and apply random numbers.

**Day 2 Information**

- MAMD = 152.9 lbs/ft³
- Avg. Compaction = 93.4%
- Avg. Volume per ton = 14.00 ft³ / ton
- Cross-Sectional Area = 2.67 ft²
- Yield = 5.24 ft / ton

<table>
<thead>
<tr>
<th>Remaining random numbers from Day 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random #</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>92639</td>
</tr>
<tr>
<td>35721</td>
</tr>
</tbody>
</table>
Example of a Partial Sublot

Using the same random tonnages computed the day before and adding 10 tons remaining from the previous segment or 3rd location will keep the distance accurate and within the 600 to 800 ton increment.

Example of a Partial Sublot

- Using the Day 1 yield factor of 5.36 ft / ton and remaining tonnage of 410 would yield a distance of 2,198’.
- Using the Day 2 yield factor of 5.24 ft / ton and remaining tonnage of 410 would yield a distance of 2,148’.
- This is a difference of 50’ or half a station reference, if MAMD and percent compaction weren't taken into account.

Day 1 – 2,198’

Day 2 – 2,148’
Non-Density Testable or Irregular Areas

- Managing of ACP placement needs to be monitored continuously during the paving operation to account for the different paving features being constructed.
- Many sections will have various widths and geometric shapes that fall under the category of non-density testable (less than 8’ in width) or irregular areas.
- These tonnages need to be separated and placed into different lots, since they aren’t density testable.
- Compute the areas using the current MAMD and average in-place compaction.

Volume of Area in ft³ x (MAMD x Compaction) / 2000 lb/ton = tonnage.

Area “a” = 5’ x 4’ / 2 = 10 sf
Area “b” = 6’ x 4’ = 24 sf
Area “b” = 8’ x 4’ / 2 = 16 sf
Total Area a+b+c = 10 sf + 24 sf + 16 sf = 50.0 sf

Depth of section 2” / 12” = 0.167 ft.
Volume in ft³ = 0.167 ft x 50.0 sf = 8.35 ft³

Tons of ACP = 8.35 ft³ x (152.9 x 0.934) / 2000 lb / ton = 0.60 tons
Non-Density Testable or Irregular Areas

- The PM / Inspector should coordinate with the QCCS and contractor, regarding separation of quantities into various categories.

- All random number determinations shall be maintained and filed with the appropriate density reports. A new form is available to assist the inspector and can be used as supporting documentation.

- If assistance is needed for random site determinations don’t hesitate to call the Regional QAC for assistance.