UNDERSTANDING & TROUBLESHOOTING COMPACTATION PROBLEMS RELATED TO TESTING & MATERIALS

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Compaction Problems Related to Testing and Materials

• Compaction…Why do we care?
• Density & Compaction Defined
• Basic Statistics
• Maximum Specific Gravity (Rice)
• Bulk Density
  – Cores
  – Nuclear Gauges
• Impacts of Materials
• Recommended Practices
Importance of Compaction

• Improve Mechanical Stability
• Improve Resistance to Permanent Deformation
• Reduce Moisture Penetration
• Improve Fatigue (Cracking) Resistance
• Reduce Low-Temperature Cracking Potential
Terminology

- In-Place Air Voids
- Compaction

In-Place Air Voids = 100 - Compaction

Compaction = 93%....In-Place Air Voids = 7%
In-Place Air Voids
Keys to Performance

DETERIORATION MECHANISMS
Rutting
Cracking
Mix Design Selection

Freeway Mix Design in Cul-de-sac

Cul-de-sac Mix design on Freeway
In-Place Air Voids & Performance
Past Studies – Air Voids < 3%
MIX PROBLEM!!!
AIR VOIDS > 8%

CRACKING

STRIPPING

MIX PROBLEM or ROLLING PROBLEM
Performance Theory

- Washington DOT Study

- For every 1% Compaction under 93%:
  - Lose 10% Fatigue Life
  - Fatigue = Alligator Cracking
Permeability

• Measure of ability to drain water

• High permeability - Drains a lot of water

• Low Permeability - Drains little or no water
Permeability
ODOT Dense Mixes

R² = 0.6634

R² = 0.621

Permeability (x10^-5 cm/s)

Air Voids

12.5 mm Dense
19 mm Dense

Series 3

Power (12.5 mm Dense)
Power (19 mm Dense)
Linear (Series 3)
Density

\[
\text{DENSITY} = \frac{\text{Mass}}{\text{Volume}} = \frac{\text{lbs}}{\text{cu ft}}
\]
Density

• Maximum Theoretical Density (Rice)
  – “Reference Density” (except for FAA)
  – Maximum Density Test (MDT)

• Bulk Density (Cores or Nuclear Gauge)
Compaction

%Compaction = \frac{\text{Bulk Density}}{\text{Max. Density}} \times 100

Most agencies require 91% or 92% minimum
Basic Statistics
Variability

Why should a test result vary?

Four sources of variation
Material
Production
Sampling
Testing

50%
Need for Statistical Analysis?

Statistics helps separate true variability in the product…

that which we are really interested in…

from variability inherent in sampling and testing methods
Scientific Tools to Use in the Treatment and Analysis of Data

• Statistics
• Random sampling
Statistics

- Average
- Standard Deviation

Normal Distribution is most important for highway materials
Normal Curves

Standard Deviation (sd) = Measure of variation or spread of data
Minimizing Sampling & Testing Variability

Consistent Procedures
Certified Technicians
Certified Labs
Calibrated Equipment

Apply Statistics
Precision Statements
Random Sampling
Multiple Tests
Applied Statistics

AASHTO & ASTM test procedures include Precision and Bias Statements

Variability of the test method only
Precision and Bias

*Precision* - repeatability of the measurement or process

*Accuracy* - how close to the truth

*Bias* - is the tendency to deviate from the true value
Precision, Bias, and Accuracy
Random Sampling

• Any portion of the population has equal chance of being selected

• Bias is introduced when judgment is used
Define “Lot” or Unit
(time, quantity, project, specification, mix design)

Number of Samples
Enough to be confident in average
Minimum = 3
Not much Statistical Advantage after 8
Recognize time and economic limitations

Selecting Locations
Random Number Tables
Computer Generated Random Number Algorithms
MAXIMUM SPECIFIC GRAVITY
Maximum Density

• What is it?
• How is it measured?
• What materials factors effect results?
• Recommendations
Maximum Density
What is it?

• Density at 100% compaction

• Rock + Oil….No Air
MDT Measurement

AASHTO T 209

- Laboratory Test
- Test Loose Sample of Mix
- Most labs capable of performing test
AASHTO T 209

INFLUENCES

Testing Variability
Asphalt Content ***
Asphalt Absorption
Aggregate Specific Gravity
MDT Testing Variability

AASHTO T 209 Precision

Single Operator

0.004 = 0.25 pcf
AASHTO T 209
100 Tests – Same Sample

151.25 pcf 151.50 pcf 151.75 pcf 152.00 pcf 152.25 pcf 152.50 pcf 152.75 pcf
(92.55%) (92.40%) (92.25%) (92.10%) (91.95%) (91.80%) (91.65%)
Maximum Density
Asphalt Content

Density (pcf) vs. Asphalt Content

- Density values range from 154 to 150 pcf.
- Asphalt content varies from 4.9 to 6.1.

The graph shows a downward trend as asphalt content increases.
Asphalt Absorption

Some aggregates can absorb substantial amounts of asphalt

Very Complicated Phenomenon

Higher Absorption = Higher Max Gravity

Higher Max Gravity = Lower Compaction
More time at high temperatures = more asphalt absorbed
Aggregate Specific Gravity
Maximum Density
Recommendations

Ideal

• 1 MDT per day, keep running average of 4 or 5 days for Compaction Testing Reference Density

• Run supplemental “Dryback” procedure for mixtures that have an asphalt absorption of 1.5% or more
Maximum Density
Recommendations

Minimums

• 1 Set of 3 tests (averaged) every calendar year for MDT reference density (plant samples are best)

• Run supplemental “Dryback” procedure for mixtures that have an asphalt absorption of 1.5% or more

• “Cure” test samples to represent average storage and delivery time
Maximum Density
Recommendations

Minimums

- Run a new set of 3 tests when:
  - Change in source aggregate material properties is suspected
  - Change in asphalt supplier
  - Storage and delivery times substantially different than “average” conditions
  - Asphalt content is suspect
  - Compaction problems
  - Dispute resolution
BULK SPECIFIC GRAVITY
Bulk Density

• What is it?
• How is it measured?
• What materials factors effect results?
• Recommendations
Bulk Density

What is it?

Mass of
Rock + Oil AND Air
in a Unit Volume
Bulk Density Measurement

Two Primary Measurement Methods

• **Cores** (physical measurement)
  – AASHTO T 166

• **Nuclear Gauges** (estimate using radioactive particle techniques)
  – WAQTC TM 8
ADVANTAGES

Physical Measurement

More Accurate than Nuclear Gauge

More Precise than Nuclear Gauge

DISADVANTAGES

Destructive

Time Consuming
CORING

Things to Remember

• Make sure mix is cool enough to drill
• Do not damage core during removal
• Do not store in direct sun
• Transport in pipe to minimize deformation
• Sawcut to isolate lift(s) of interest
Bulk Density

INFLUENCES

Testing Variability
Asphalt Content ***
Asphalt Absorption
Gradation
Aggregate Properties
Bulk Density Measurement

AASHTO T 166 Precision

No Official Precision Statement

3 Cores Minimum per Unit

5 – 8 Preferred
Fills Voids between Aggregate Particles
Maximum Density
Asphalt Content

Density (pcf)

Asphalt Content
Compaction
Asphalt Content

% Compaction

Asphalt Content
More time at high temperatures = more asphalt absorbed
Typical Oregon Gradation

Finer (more passing #8) = Higher Compaction
Coarser (less passing #8) = Lower Compaction
In General....
1% more Dust = 1% more Compaction

Too Much or Too Little Dust......
TENDER MIX!!
Mat Tears
Other Aggregate Properties

Fracture
Shape
Texture
RAP
Aggregate Fracture
Aggregate Texture
Bulk Density Cores

Recommendations

• Take 3 to 8 Random Cores for Area of Interest to get a Good Average Density

• Core Before Traffic if Possible
Compaction Problems
Factors Effecting Bulk Density

**Materials Checklist**

- Asphalt Content?
- Storage/Haul Time?
- Asphalt Grade?
- Gradation?
- Dust?
- Other Aggregate Properties?
NUCLEAR GAUGES

- How they work
- Testing Variability
- Common Problems
- Gauge Checklist
ADVANTAGES
- Fast
- Non-Destructive

DISADVANTAGES
- Less Precise than Cores (not a physical measurement)
- Error Prone
- Safety
Backscatter Densometer

Americium Source

Surface

Cesium Source

Gauge

Detectors

Photon Paths

3" – 3.5"

Cesium for Density Determination
Americium for Moisture Determination
Potential Effects of Lift Thickness

Lift Thickness 1.5”

Depth of Gauge Reading 3”

<table>
<thead>
<tr>
<th>Layer</th>
<th>Density (pcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMAC</td>
<td>145</td>
</tr>
<tr>
<td>Agg Base</td>
<td>125</td>
</tr>
<tr>
<td>HMAC</td>
<td>145</td>
</tr>
<tr>
<td>Agg Base</td>
<td>125</td>
</tr>
</tbody>
</table>
Nuclear Gauge Precision
1 Minute Counts

-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

138.0 pcf (90.8%)
138.6 pcf (91.2%)
139.2 pcf (91.6%)
139.8 pcf (92%)
140.4 pcf (92.4%)
141.0 pcf (92.8%)
141.6 pcf (93.2%)

66 out of 100
95 out of 100
Nuclear Gauges
Minimizing Testing Variability

• Use at least 1 Minute Count
• Sand Test Locations
• Take 2 Tests at Each Location
  – If 2 tests differ by more than 2.5 pcf, retest
  – If within 2.5 pcf, compute average
• Test 3 to 8 Locations per Unit
Nuclear Gauges
Common Problems

• Gauge Calibration
• Gauge in Wrong Mode (Wet vs Dry Density)
• Wrong Reference Density Used
• Handle Not Locked in Proper Position
• Gauge Not Seated Properly (air gaps)
• Moisture in Gauge
• Bias in Gauge Readings
  – Core Correlate
Core Correlations

Used to develop correction factor to adjust Gauge Readings to more closely match Core (physical) measurements.
Core Density vs Nuclear Density
General Relationship
Core Correlations

• Select minimum of 8 locations
  – Locations to represent a range of densities
  – Typically various locations transversely across mat
• Test with Gauge
• Core/Test for Bulk Density
• Develop Correction Factor
  – Each correlation is unique to an individual gauge
• Apply factor to Gauge Readings
Core Correlations

Consider a New Correlation if:

• Lift Thickness Changes
• Underlying Material Changes
• Aggregate Material Source Changes
• Substantial Mix Design Changes
• Gauge Recently Calibrated
• Technician Certified
• Standard Count Performed Daily
• Correct Reference Density Entered
• Proper Test Time
• Gauge in Asphalt Mode (Wet Density)
• Gauge in Backscatter Position
Nuclear Gauge
Checklist

• Bottom of Gauge Clean
• Sanded Locations (Air Gaps?)
• Handle in Proper Position
• 2 Tests within 2.5 pcf at each location
• Gauge Display Fogging Up?
  – Don’t leave Gauge on hot mat for extended period
• Consider Core Correlation
WRAP-UP

• Get Enough Tests to Minimize Testing Variability and be Confident Materials Properties are Accurately Represented

• Assure Materials Information is Current, Precise and Accurate
  – Maximum Density (Rice)
  – Bulk Density (Cores)
  – Nuclear Gauge
    • Core Correlation
WRAP-UP

• Paving Crews/Inspectors: Communicate Frequently with QC or QA Staff and Plant Staff
  – Asphalt Content Changes
  – Gradation Changes
  – Storage and Delivery Times
  – Testing Concerns

• Compaction is CRITICAL to performance
ADEQUATE COMPACTIVE EFFORT?

Figure 1

Average - All Highways = 9.5 Passes
Average - Freeways Only = 9.6 Passes
Average - Non Freeways = 9.4 Passes

# of Control Strip

Total Roller Passes

- All Highways
- Freeways Only
- Non Freeways
Get Compaction!!!

• If you are making 8 – 12 passes
• If the mix is compacted in the right temperature range
• If the gauge is providing good information
• And you’re **FAILING** compaction.....
ADJUST THE MIX

NOW!!

If you can’t get anyone’s attention, then hit the STOP button