Compaction

“Victorious warriors win first and then go to war, while defeated warriors go to war first and then seek to win.”
—Sun-tzu

Asphalt Institute
MS-22
Chapter 6-Compaction

What is Compaction?

The process of reducing the volume of a given mass of material.
Compaction Illustrated

Compaction

• Vital for Good Performance
• Compaction Goal
  – 4-8% Air Voids (Conventional Mixes)
  – 3-6% Air Voids (Coarse or Gap Graded Mixes)
• Requirements for Compaction
  – Compactive Effort
    • Use the right rollers
  – Good Mix Temperatures (Workable)
  • Haul length
  • Ambient conditions
  – Mixture Confinement
    • Lift thickness
    • Base support

Compaction Goals

• Increase stability
• Reduce air voids
• Provide a smooth surface
Factors Affecting Compaction

- Mixture properties
- Ambient conditions
- Lift thickness
- Base/subgrade support (confinement)
- Compactive effort

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Mixture Properties

- Materials characteristics
  - Asphalt binder
  - Aggregates
- Mix design
  - Aggregate structure
  - Volumetric properties
- Production variables
  - Moisture content
  - Temperature
Asphalt Binder Properties

- Binder grade
  - Increase high temperature grade → stiffer binder
  - Neat or modified?
    - PG grades with 92°C or more temperature difference are usually polymer modified
- Temperature
  - Must complete compaction while mix temperature exceeds:
    - 85°C (185°F) for neat binders
    - 100°C (212°F) for modified binders
    - 70°C (158°F) for warm mix binders?

Polymer-Modified Asphalt

- Stiffen at much higher temperatures than neat asphalt
  - Reduce time available for compaction by half
- When specifying binders that will likely be polymer-modified (PG 70-28, PG 76-22, etc.)
  - Avoid requiring compacted lift thickness less than two inches

Aggregate Properties

- Physical properties
  - Gradation
  - Angularity
Contrasting Stone Skeletons

Angular Aggregate

Rounded Aggregate

Mixtures designed to resist rutting will also resist compaction!!!

Compaction

• Moisture Content
  – Lubricants → tenderness
  – Most common with:
    • Drum plants
    • Mixes with RAP
    • Absorptive aggregates
    • Stockpiles that have been sitting
Factors Affecting Compaction

- Mixture properties
- Ambient conditions
- Lift thickness
- Base/subgrade support (confinement)
- Compactive effort

Ambient Conditions

<table>
<thead>
<tr>
<th>Mat Thickness</th>
<th>Base Temperatures (Minimum)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Degrees F</td>
</tr>
<tr>
<td>3 inches or greater</td>
<td>40</td>
</tr>
<tr>
<td>1-3 inches</td>
<td>45</td>
</tr>
<tr>
<td>Less than 1 inch</td>
<td>50</td>
</tr>
</tbody>
</table>

AK specs—40°F and rising

Factors Affecting Compaction

- Mixture properties
- Ambient conditions
- Lift thickness
- Base/subgrade support (confinement)
- Compactive effort
Compaction

- Temperature
  - Generally – hotter is better
  - But – heat ages the mixture
  - Thicker lift holds heat better
    • An extra 1.0 cm gains 6-7 minutes of compaction time
    • Generally – lift should be three times the nominal maximum aggregate size

MS-22, Table 6.03

- Increasing the lift thickness by 1.0 cm adds 6-7 minutes to available compaction time.
Suggested Lift Thickness Ranges, P-401 (FAA)

<table>
<thead>
<tr>
<th>Max. Aggregate Size</th>
<th>Suggested Lift Thickness, in minimum</th>
<th>maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1¼ inch</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>1 inch</td>
<td>2½</td>
<td>4</td>
</tr>
<tr>
<td>¾ inch</td>
<td>1¼</td>
<td>3</td>
</tr>
<tr>
<td>½ inch</td>
<td>1½</td>
<td>2½</td>
</tr>
</tbody>
</table>

Do not specify lifts thinner than 1½ inch (40 mm)

AK Specs??

Factors Affecting Compaction

- Mixture properties
- Ambient conditions
- Lift thickness
- Base/subgrade support (confinement)
- Compactive effort

Confinement

- Stable platform
- Good grip on underlying surface
  - Clean surface
  - Properly tacked
- Use temperature to confine edges
  - Delay rolling unsupported edge to allow “internal confinement” to develop
Factors Affecting Compaction

- Mixture properties
- Ambient conditions
- Lift thickness
- Base/subgrade support (confinement)
- Compactive effort

Compaction Equipment

- Screed
  - Screed weight
  - Screed vibration
  - Tamper bar
- Rollers
  - Vibratory steel
  - Pneumatic
  - Static steel
  - Combination
Tamper Bar

Moves up and down tamping mix under the screed

Rolling Procedures

• Breakdown rolling
  – Provides nearly all needed density
• Intermediate rolling
  – Provides final density level
  – Seals surface
• Finish rolling
  – Removes roller marks

Rollers

• Vibratory
  – Used for breakdown (initial) compaction
  – Offers greatest compactive effort
  – Speed of roller needs to match its frequency
Amplitude & Frequency

Amplitude = f (drum weight, eccentric moment, frequency)
Amplitude is calculated, not measured value.

Time between blows, t

F = 1/t

Checking Frequency

Contractors and Inspectors should have a Reed Tachometer available

Vibratory Rollers

- Commonly used for initial (breakdown) rolling
- 8-18.5 tons, 57-84 in wide ("heavy" rollers)
  - 50-200 lbs/linear inch (PLI)
- Frequency: 2700 - 4200 impacts/min.
  - Trend to increase frequency
- Amplitude: 0.4 - 0.8 mm
  - For thin overlays (< 150 mm) use lowest amplitude setting or static mode
- Operate to attain at least 30 impacts/meter
  - 3-6.5 km/hr
Why are vibratory rollers more effective?

- Movement of drum initiates particle motion
- Resistance to deformation is much less when particles are moving than when static (inertia)
- Force applied by weight of drum has greater effect, thus achieving more compaction per pass than other roller types

Roller Speed Comparison

<table>
<thead>
<tr>
<th>Number of Passes</th>
<th>Density</th>
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<tbody>
<tr>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>1</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td>95</td>
</tr>
<tr>
<td>4</td>
<td>95</td>
</tr>
<tr>
<td>5</td>
<td>95</td>
</tr>
</tbody>
</table>

- Red line: 1.7 MPH
- Blue line: 2.8 MPH
Frequency vs. Travel Speed

<table>
<thead>
<tr>
<th>VPM</th>
<th>2 mph</th>
<th>2.5 mph</th>
<th>3 mph</th>
<th>3.5 mph</th>
<th>4 mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>11.4</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2500</td>
<td>14.2</td>
<td>11.4</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>3000</td>
<td>17.0</td>
<td>13.3</td>
<td>11.4</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>3500</td>
<td>19.9</td>
<td>15.9</td>
<td>13.3</td>
<td>11.4</td>
<td>10.0</td>
</tr>
<tr>
<td>4000</td>
<td>22.7</td>
<td>18.2</td>
<td>15.2</td>
<td>13.3</td>
<td>11.4</td>
</tr>
</tbody>
</table>

What happens if you operate the roller too fast?

- < 10 impacts per foot causes separated impacts
- Result is a washboard/rippling pattern that can’t be rolled out
- Most easily seen with low-angle light
  - Early or late in day
  - Headlights from vehicles

Pneumatic Roller
Rubber Tire Manipulation

- Overlap manipulates mat under and between tire
- Tight finish resists moisture penetration
- Manipulation increased by lowering tire pressure
- Static force increased by high tire pressure

Pneumatic Roller

- Generally used as intermediate roller
- Reorients particles through kneading action
- Load/tire: 1050 – 6730 #/tire depending on model/ballast
- Tire pressure of ~70 psi—must be consistent
- Be sure to ballast
- Tires must be hot to avoid pickup
- Use skirts

Compaction Issues - Tire Pick-up

- Once tires hot - keep them hot
- Develop good rolling pattern - never stop rolling
- If waiting for trucks, roll on previously compacted mat
Static Steel-Wheeled Rollers

- 10-14 ton rollers normally used for HMA compaction
  - Commonly use vibratory rollers operated in static mode
- Lighter rollers used for finish rolling
- Drums must be smooth and clean
- For initial compaction, drive wheel must face paver

Test (Control) Strip

- At least 300 feet long, two "pulls" wide
- Closely Simulate Paving Conditions
  - Base conditions
  - Haul times
  - Mixture storage
  - Paver speed
  - Joint construction
- Monitor Compaction After Each Pass
  - Density will climb, then peak, then fall
Establishing Rolling Pattern

- Speed & lap pattern for each roller
- Number of passes for each roller
  - One trip across a point on the mat
- Minimum temperature by which each roller must complete pattern

**IMPORTANT:**

Paver speed must not exceed that of the compaction operation!!!

Rolling Pattern

- Speed & lap pattern for each roller
- Number of passes for each roller
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- Minimum temperature by which each roller must complete pattern

**IMPORTANT:**

Paver speed must not exceed that of the compaction operation!!!

General Rules

- Avoid Stopping and Sitting on Hot Mat
- Never Turn a Stopper Roller
- Angle all Stops
Improving Quality Control with Intelligent Compaction

Build a better mousetrap and the world will beat a path to your door. - Ralph Waldo Emerson

How Does IC Help with QC?

- “Real-Time” Feedback to Roller Operator
  - On-Board, Color-Coded Mapping
    - Improved roller patterns
    - Improved temperature control
    - Ability to make adjustments “on-the-fly”
- Permanent Records of Compaction Data
- “Mapping” of Underlying Materials
  - RMV (Roller Measurement Values) readings
    - Locates “soft spots”
    - Identifies irregular support for compaction

Why Do We Need IC?

- Conventional compaction equipment and procedures have shortcomings and too often produce poor results
- Intelligent compaction technology appears to offer “a better way”
Improving QC with IC

• Shortcomings in Density Acceptance Process…

IC Pooled Fund (ICPF)

ICPF States / Year

What is Intelligent Compaction?

Vibratory Single Drum Soil Roller

Vibratory Tandem Drum Asphalt Roller
IC Roller Requirements

• IC Roller Requirements
  – Roller Measurement Value (RMV)
  – GPS-Based documentation system
  – Color-coded display (on-board)
  – Surface temperature measurement system
  – Optional: automatic feedback system

Color-Coded On Board Display

Global Positioning System (GPS)

Real Time Kinematic (RTK) GPS Precision
Mat Surface Temperature Measurement

Infrared Thermal Gauge

Improving QC using IC

“Real-Time” Feedback to Roller Operator

Sakai Project - CA

• Roller Passes
  Shoulder (Supported)
  Paving Direction
  Longitudinal Joint

Courtesy Sakai America
Roller Operator Training

Improved Rolling Patterns

Sakai IC roller

Improved QC using IC

Permanent Records of Compaction Related Data and Data Analysis
Improving QC using IC

“Mapping of Underlying Layers Prior to Paving

“Mapping” of Underlying Materials

• Use of RMV color-coded mapping to measure support prior to paving of:
  – Subgrade soil materials
  – Stabilized subbase materials
  – Aggregate base materials
  – Existing asphalt pavements
  – Rubblized concrete pavements
• Underlying Support affects compatibility of subsequent layers

“Mapping” of underling layers

Mapping of the subgrade / agg. base layer

Minnesota ICPF Project
Future Research Needs - IC

- Improve correlation of Density vs. RMV
- Standardization of RMV
- Explore GPS Technology
  - Use of advanced, high prec. GPS technology
  - “Stand-Alone” (non RTK) GPS Technology
- IC Data Management
  - Improvements in on-board roller software
  - Data collection/storage
  - Data analysis/reporting

Summary

- Intelligent Compaction is a major innovation in compaction technology
- Research/field projects show that IC can offer a valuable tool to improve QC of the compaction process
- IC technology is now readily available in U.S.
- More work is need to address various issues
- Stay tuned!

We’ve Come a Long Way

1924 Buffalo Springfield Steam Roller
Questions?