Quality Control for Concrete Paving: A Tool for Agency and Industry

• QC by contractors, concrete suppliers, and material suppliers is an integral part of an agency’s QA program

• QC includes:
  - operational level programs
  - project-level QC plans

• QC provides many benefits to both agency and contractor

QC by contractors, concrete suppliers, and material suppliers is an integral part of an agency’s QA program. QC includes operational level programs and project-level QC plans. QC provides many benefits to both agency and contractor.

This document includes information necessary for contractors to:

• understand common agency QC requirements,
• develop and implement the appropriate tools, processes, and procedures to meet these requirements,
• develop and implement continuous improvement activities to improve their ability to meet agency QA requirements, and
• recognize that good quality control will lead to a number of benefits including higher efficiency and productivity, increased profit, and safer operations.
Overview

- Section 1: Introduction
- Section 2: Introduction to QC, organizational-level QC
- Section 3: QC for suppliers of materials for concrete pavements
- Section 4: Introduction to PEM, QC processes supporting PEMs
- Section 5: QC methods for concrete pavement construction
  - mixture design, mixture verification/field setup, mixture and construction QC, construction acceptance.
  - best practices to support development of a QC plan
- Section 6: QC tools
  - checklists, control charts and process adjustments, records management

Section 1: Introduction

- Overview of the guide
- Message to Agencies
  - Agencies gain many benefits from contractor QC:
    - improved quality of construction as contractors enhance their QC plans
    - an increased confidence in contractor QC data, and use of QC data in the agency’s QA program
    - confidence to consider loosening or removing restrictive prescriptive specifications
    - confidence to consider implementing performance-type specifications

It is hoped that this guide helps agencies develop, improve, or enhance their specifications and QA provisions regarding contractor QC

- financial incentives tied to QC are encouraged
- aim to relax or eliminate restrictive prescriptive specifications, move to performance-type specifications

- Appendix A: list of QC requirements commonly/less commonly specified

Appendix A: Review of Agency QC Requirements

- Common requirements are provided in standard font
- Less commonly specified requirements in italics

2. QC Requirements for Concrete Mixture Components
   Material sources and information regarding their status in the agency’s qualification program(s).
   - Sampling techniques for components of concrete
   - Aggregates
     - Specific gravity
     - Absorption
     - Gradation
     - Abrasion resistance
     - Percent passing No. 200
     - Fractured faces
     - Verification of non-alkali-reactive materials
   - Cement and supplementary cementitious materials
     - Mill test reports
     - Material composition test results
     - Supplier material certification or other information to ensure material is an agency approved product
   - Admixtures and other materials used in concrete
     - Supplier material certification or other information to ensure material is an agency approved product
Section 1: Introduction

- **Definitions** from 23 CFR 47, TRB Glossary, and those specifically used in this document
  - QC Program, QC Plan, QC Process
- **Elements of a QA Program**

![Diagram of QA Program](image)

Figure: Dennis Dvorak, FHWA

Section 2: Quality Control Fundamentals

- **Introduction to QC**
  1. **PLAN**
     - identify problems
     - define desired outcomes
     - identify potential solutions
     - develop policies and procedures
  2. **DO**
     - test potential solutions
     - create process structure
     - establish systems
     - conduct training
     - measure quality characteristics
     - collect data
  3. **CHECK**
     - monitor and analyze data
     - study the results
     - draw conclusions
  4. **ACT**
     - identify lessons learned
     - implement the most promising corrective and preventative actions

"Any product, process, or service can be improved, and a successful organization is one that consciously seeks and exploits opportunities for improvements at all levels." (Swift et al. 1998)

Section 2: Quality Control Fundamentals

- **Organizational Quality Management**
  - Contractor QC programs include the procedures and practices that occur continuously, supporting the QC required for each project.

These formal practices and procedures should support (Taylor et al. 2019):
- personnel training
- laboratory certification
- standardization of processes and best practices
- procurement of products and services
- preliminary material testing
- equipment and process monitoring
- communication and information flow
- documentation and recordkeeping
- control of documents

Section 2: Quality Control Fundamentals

- **Communication**
  - QC relies upon good communication - written, spoken, email, text messages, paper documents, electronic files, software, models
  - Refers reader to Appendix B: Poor, fair, and good QC plan provisions

**Aggregate stockpile management:**

- **Good**: Aggregate stockpiles will be laid out in a manner that provides for adequate drainage away from the area. Swales and erosion control materials will be used to direct runoff as required. Prior to establishing stockpiles, the integrity of the subgrade soils will be verified and stabilized if necessary. Haul trucks used to bring aggregates to the site will be unloaded in a designated area adjacent to the stockpiles. Aggregates will then be transferred to the stockpile using a wheeled loader. Stockpiles will be maintained in a manner that minimizes segregation and prevents contaminant material from being introduced. Stockpiles will be visually inspected daily by the QC manager to ensure they are in good condition and to identify remedial actions, if necessary.
Section 2: Quality Control Fundamentals

• Quality Control Plans

Objective of QC Plan:
to establish a framework of activities and actions that, when implemented over the course of a project, will enable a contractor to reduce the risk of out-of-specification work, along with associated delays, costs, and impacts to reputation.

• Contractor should view QC plan as a highly beneficial tool
• List/description of typical elements
  • parties/personnel and roles/responsibilities
  • materials, tests, methods, sampling plan
  • monitoring/inspection activities
  • procedures for evaluating data
  • means for maintaining control of work
  • corrective actions
  • documentation required
• *** discussion on choosing appropriate quality characteristics to help support acceptance

Section 2: Quality Control Fundamentals

• Understanding Variability
  • Sources of variability
    • Chance cause (natural) variability vs. assignable cause (not natural) variability

Section 2: Quality Control Fundamentals

• Sampling and Statistical Process Control
  • Guidance to develop a sampling plan that is comprehensive, reliable, cost-effective, useful and understood
  • Random sampling (upper) vs. Time order sampling (lower)

A sampling plan must be sufficiently robust to support production/construction of a quality product, at a reasonable cost, with an acceptable level of risk to the manufacturer or contractor.

Section 3: Supplier QC for Concrete Pavement Materials

• QC plan should ensure contractor knows and understands:
  • the specifications for all the products being supplied
  • how to measure the required uniformity of the products being supplied, and adjustments to make to the process if the uniformity changes.

• Provides supplier QC practices/tests/documentation for:
  • portland cement and blended cements
  • SCMs
  • admixtures
  • aggregates

• Emphasis on:
  • how to understand uniformity/variability
  • communication with suppliers

• External resources provided
Section 4: Performance Engineered Concrete Mixtures

- Introduction to PEM and AASHTO PP 84
- Links between QC and PEM
- Summary of PEM requirements
  - Strength
  - Reducing unwanted warping and cracking due to shrinkage
  - Freeze-thaw durability
  - Transport properties (permeability)
  - Aggregate stability
  - Workability
- Provides list of PEM test methods for each requirement
- Provides a recommended approach for contractor QC

With respect to QC, it should not matter whether a pavement is constructed under PEM specifications or traditional concrete pavement specifications.

Section 5: QC for Concrete Pavement Construction

- Implementation of a QC Process
  - Mixture design (prequalification)
  - Mixture verification (field setup)
  - Mixture production and construction QC
  - Mixture and construction acceptance

- Each stage is described
- A framework is provided, showing QC items associated with each stage
- Subsequent sections describe each phase of paving, associated QC activities

Section 5 is heavily based on materials presented in:
- Field Reference Manual for Quality Concrete Pavements (Fick et al. 2012)

Section 5: Example Framework for Pavement Construction QC

<table>
<thead>
<tr>
<th>Item</th>
<th>Mixture Design (prequalification)</th>
<th>Mixture Verification (field setup)</th>
<th>Mixture and Construction QC</th>
<th>Mixture and Construction Acceptance</th>
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</thead>
<tbody>
<tr>
<td>QC Plan</td>
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<tr>
<td>Determination of Mixture Materials</td>
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<td>Aggregate Grading</td>
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<td>Temperature Sensitivity of Mixture</td>
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<td>Mixture Properties (Example for PEM shown)</td>
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<tr>
<td>As specified</td>
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<tr>
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<td>✓</td>
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</tr>
<tr>
<td>Compressive strength at 3 and 7 days</td>
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<td>Unit weight</td>
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<td>Mixture Production</td>
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<td>Stockpile Management</td>
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<td>Adjustment of admixture dosages</td>
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<td>Minor reproportioning of aggregates</td>
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<td>Heating or cooling the mixture</td>
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<td>Mixture and Construction QC</td>
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<td>Paving</td>
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<td>Sawing Joints</td>
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<tr>
<td>Sealing Joints</td>
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<td>Backfill Pavement Edges</td>
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<tr>
<td>Open to Constr. Traffic</td>
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</tr>
<tr>
<td>Open to Public Traffic</td>
<td>✓</td>
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</tr>
</tbody>
</table>
Section 5: QC Guidance for Each Step of Process

Staking and Stringline or Stringless QC

Key inspection items
- Spot check paving hubs and grades for accuracy by checking against a known benchmark.
- Visually inspect stringline for abrupt changes and/or discontinuities (stringline only).
- Check that pins and wands are solid and resistant to moving (stringline only).
- Depending on the offset used, subgrade and subbase that has pumped may move the paving hub from its surveyed elevation and alignment. Correct the subgrade/subbase and re-survey.
- Random check of stringline elevation and alignment relative to paving hub information (not applicable to string which has been eyeballed adjusted for smoothness) (stringline only).

QC measurements
- Staking and stringline
- Stringless

Checklist
- Staking and stringline
- Stringless

Key inspection items
- Verify the survey has provided the correct grade of the requested offset and grade type (projected or level).
- Pins are placed at appropriate intervals (25 ft or less in tangent sections, closer spacing through tight curves).
- Wands are adjusted for alignment (stringline should be directly above the hub).
- Stringline is set to the correct elevation with respect to the hub.
- Stringline is uniformly taut.
- Stringline is marked for visibility to prevent accidental bumping.
- PINS are placed at appropriate intervals (25 ft or less in tangent sections, closer spacing through tight curves).
- Stringline is set to the correct elevation with respect to the hub.
- Stringline is uniformly taut.
- Stringline is marked for visibility to prevent accidental bumping.

QC measurements
- Stringline and paving hub alignment (from Minnesota DOT)

Section 5: QC Guidance for Each Step of Process

Dowel Basket QC

Key inspection items
- Dowel baskets
- Dowel basket anchored to slabs (upper) and existing asphalt (lower, from Maria Masten, Minnesota DOT)

QC measurements
- Dowel baskets

Checklist
- Dowel baskets

Key inspection items
- Embedment of the cover of bars should be verified by probing behind the paver at 300 ft intervals (at least 1 bar for each basket across the width of the slab should be located).
- Non-destructive devices such as the MIT Scan, MIT Scan T2, ground penetrating radar or pachometer (cover meter) can be used to evaluate dowel-joint placement.

QC measurements
- Dowel baskets

Checklist
- Dowel baskets

Section 5: QC Guidance for Each Step of Process

Mixture Production QC

Key inspection items
- Review aggregate moisture testing and moisture compensation on the batch tickets.
- Periodically monitor mixing time.
- Check that the aggregate moisture contents used for adjusting batch proportions is representative of the material being taken from the stockpiles.
- Aggregate analysis and combined gradation.
- Aggregate moisture content.
- Concrete temperature*.
- Unit weight*.
- Air content*.
- * at a minimum, each of these quality measurements should be checked randomly every 1,000 cubic yards at the plant site and compared to samples obtained at the point of delivery. Other PEM tests should be included to ensure agency specifications are met, or at the discretion of the contractor.

QC measurements
- Mixture production

Checklist
- Mixture production

Other
- Mix proportion refresh
- Material inventories are adequate.
- Mixing drum is clean of dried materials which could break loose.
- Mixing blades are not overly worn.
- Spot check paving hubs and grades for accuracy by checking against a known benchmark.
- Visually inspect stringline for abrupt changes and/or discontinuities (stringline only).
- Check that pins and wands are solid and resistant to moving (stringline only).
- Depending on the offset used, subgrade and subbase that has pumped may move the paving hub from its surveyed elevation and alignment. Correct the subgrade/subbase and re-survey.
- Random check of stringline elevation and alignment relative to paving hub information (not applicable to string which has been eyeballed adjusted for smoothness) (stringline only).

Section 5: Recommended laboratory tests for each stage

- Mixture prequalification tests
- Field setup tests
- Mixture QC tests (table shown below)
- Mixture Acceptance

<table>
<thead>
<tr>
<th>Concrete property</th>
<th>Test description</th>
<th>Test method</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workability</td>
<td>Aggregates gradation</td>
<td>ASTM C136 / AASHTO T 27</td>
<td>Use the individual gradations and proportions to calculate the combined gradation</td>
</tr>
<tr>
<td></td>
<td>Combined gradation</td>
<td>Tarantula curve</td>
<td>Monitor uniformity</td>
</tr>
<tr>
<td></td>
<td>Aggregates moisture content</td>
<td>ASTM C29</td>
<td>Affects w/cm ratio and workability</td>
</tr>
<tr>
<td></td>
<td>Slump</td>
<td>ASTM C143 / AASHTO T 119</td>
<td>Indicate uniformity batch to batch</td>
</tr>
<tr>
<td></td>
<td>Super Air Meter (SAM)</td>
<td>AASHTO TP 118</td>
<td>Indicate uniformity batch to batch</td>
</tr>
<tr>
<td>Air void system</td>
<td>Unit weight</td>
<td>ASTM C39 / AASHTO T 22 and/or ASTM C79 / AASHTO T 97</td>
<td>Indicate uniformity batch to batch</td>
</tr>
<tr>
<td></td>
<td>Unit weight</td>
<td>ASTM C138 / AASHTO T 121</td>
<td>Indicate uniformity batch to batch</td>
</tr>
<tr>
<td>Strength development</td>
<td>Maturity</td>
<td>ASTM C1074</td>
<td>Opening times</td>
</tr>
<tr>
<td>Transport</td>
<td>Resilience/F- Factor</td>
<td>Soak/store samples in salt solution</td>
<td>Monitor over time</td>
</tr>
<tr>
<td>Other</td>
<td>Hydration</td>
<td>Semi-adiabatic calorimetry</td>
<td>Indicates uniformity batch to batch</td>
</tr>
</tbody>
</table>

*Air content, Unit weight, and the other elements noted above may be tested at the discretion of the contractor.
Section 5: Acceptance

• Summary of acceptance tests (table shown below)

<table>
<thead>
<tr>
<th>Property</th>
<th>Construction QC</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test method / comments</td>
<td>Test method</td>
</tr>
<tr>
<td>Vibration monitoring</td>
<td>On board monitors</td>
<td>On board monitors</td>
</tr>
<tr>
<td>Thickness</td>
<td>Probe behind paver</td>
<td>MIT-SCAN-T3</td>
</tr>
<tr>
<td>Smoothness</td>
<td>Real-time smoothness monitoring</td>
<td>Hardened smoothness – inertial profiler</td>
</tr>
<tr>
<td>Dowel alignment</td>
<td>MIT-DOWEL-SCAN</td>
<td>MIT-DOWEL-SCAN</td>
</tr>
</tbody>
</table>

Appendix C: QC Plan Outline

• QC plans reviewed from several contractors
• QC Plan Outline is generic
  • Can serve as a checklist of items that can be considered when developing a new QC plan or enhancing an existing plan
  • Presented in a bulleted outline format
  • Suggested typical content for each section is provided

Appendix D: Model QC Plan

• Heavily based on the Typical “Model Quality Control Plan” prepared by the NorthEast Transportation Training and Certification Program (NETTCP 2009)

• 10 Section format
  • Terms and Definitions (optional)
  • Scope and Applicable Specifications
  • Quality Control Organization
  • Quality Control Laboratories
  • Materials Control
  • Quality Control Sampling and Testing
  • Production Facilities
  • Field Operations
  • Appendices

Model QC plan will need to be modified to suit the needs of the project, the requirements of the agency, and preferences of the contractor.

Appendix D: Model QC Plan

4. Quality Control Sampling and Testing

1. Materials Control

- On board monitors
  - Monitor that all vibrators are operating
  - Ensure vibrator speed is appropriate for paver speed

- MIT-SCAN-T3 (upper) and MIT-DOWEL-SCAN (lower, both from Kessler Soils Engineering Products)
Example Sampling and Testing Table

<table>
<thead>
<tr>
<th>Material</th>
<th>Test/Test Method</th>
<th>Lot Size</th>
<th>No. of Sublots</th>
<th>Testing Frequency</th>
<th>Sampling Location</th>
<th>Sampling Method</th>
<th>Report Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse and fine aggregates</td>
<td>Gradation - ASTM C136</td>
<td>5,000 SY</td>
<td>5</td>
<td>1 per sublot and/or minimum 1 per day</td>
<td>Stockpile</td>
<td>Random, per agency specification</td>
<td>Tabular and graphical: % retained, Tarantula</td>
</tr>
<tr>
<td>Fresh concrete</td>
<td>Air content - ASTM C231</td>
<td>5,000 SY</td>
<td>5</td>
<td>First 3 loads per day and repeat for 3 loads whenever admixture dosages are adjusted</td>
<td>1. Plant Grade</td>
<td>Based, start of day</td>
<td>Tabular and control chart</td>
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<tr>
<td></td>
<td>SAM - AASHTO T 152</td>
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<td>5</td>
<td>First 3 loads</td>
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<td>1. Plant Grade</td>
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Example lot sizes, sublots, and sampling and testing frequencies from several states’ specifications are provided

Section 6: Tools for QC

What gets measured gets managed...

- Contractors are encouraged to develop a set of QC tools to support the practices included in their QC program and QC plans
- Process diagrams, checksheets, and other tools
- Cloud-based tools (e-ticketing, other software tools)
- Records management guidance

Section 6: Run Charts and Control Charts – Guidance for Development and Use

- Run charts and control charts allow a user to quickly
  - evaluate the suitability of a material or product
  - identify trends, and
  - assess whether a process is in control

- Section 6 provides guidance and examples for:
  - selecting a quality characteristic for a chart
  - developing sampling plan
  - constructing a chart
    - central line and limits established using specification-based targets (run chart)
    - central line and limits established using statistical methods (control chart)
  - observing and understanding trends in run/control charts
  - Appendix E: in-depth statistical control-chart example
Section 6: Control Charts – Trends that suggest assignable cause variability

Closing

- Contractor QC is an integral part of QA
- Agencies have various requirements for QC, but those requirements are only minimum provisions
- A successful QC program/plan
  - engages the appropriate personnel
  - manages the necessary processes
  - measures what matters, and
  - uses the appropriate test methods.
- QC required for each project will differ, and approaches will be unique to the contractor
- QC programs achieve success over time, and provide benefits to both agency and contractors

Tech Briefs

- Shorter publications
- Targeted at contractor audience
- Focused material from components of the guide

Tech Brief 1 (tentative):

QC Plans for Concrete Paving

- Introduction (sourced from Ch 1)
- Elements of a QA Program (sourced from Ch 1)
- Organizational-level QC (sourced from Ch 1)
- QC Plan Overview (sourced from Ch 2)
- Components of a QC Plan (sourced from Appendix C/D)
  - Provide QC Plan framework and reference back to full publication
  - Implementing /using/modifying plan
- Closing
Tech Brief 2 (tentative): QC for Concrete Paving with PEM

- Introduction
  - Performance Engineered Concrete Mixtures (sourced from Ch 4)
  - QC benefits
- QC for Concrete Pavement Construction (sourced from Ch 3/5)
  - Abbreviated from Chapter 5 of guide
  - Sampling and testing plan – development and example
  - Provide sample inspection items/QC measurements/checklists
  - References to full QC publication and IMCP
- Closing

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<th>Test/ test method</th>
<th>Lot size</th>
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<th>Testing frequency</th>
<th>Sampling location</th>
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Tech Brief 3 (tentative): QC Tools for Concrete Paving

- Introduction (sourced from Ch 1)
- Process diagrams, check sheets, and other tools (sourced from Ch 4)
- Run charts and control charts (sourced from Ch 6)
  - Run charts
  - Control charts
  - Other statistical methods
- Closing (sourced from Appendix E)

Acknowledgements

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- FHWA – Mike Praul, Gina Ahlstrom, Jagan Gudimettla
- CP Tech Center – Peter Taylor, Gordon Smith, Steve Tritsch, John Adam, Sharon Pronchnow
- Technical Advisory Committee

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<th>State Agencies</th>
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<tr>
<td>Maine DOT – Rick Bradbury</td>
<td>Rieth-Riley – Pete Capon</td>
<td>ACPA – Leif Wathne, Gary Mitchell</td>
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<td>Michigan DOT – John Staton</td>
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<td>Illinois Tollway – Cindy Williams</td>
<td>Mike Praul, Sam Tyson, Dennis Dvorak, Jeff Withee, Bob Conway</td>
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Questions?

- Tara Cavalline, UNC Charlotte – tcavalline@uncc.edu
- Gary Fick, Transtec – gary@thetranstecgroup.com
- Al Innis, Consultant – allison.innis@gmail.com
Hi-Way Paving

- Mike Boyle, Senior Estimator
- Rob Truman, Quality Control Manager

- QC Tests Have Eliminated Penalties From QA Test Outliers & QA Testing Errors
- QC Testing Includes Checking Subgrade (Depth Checks) to Identify High Spots to Avoid Thin Pavement-Check Prior to Paving (GSI or Stringline)
- QC Aggregate testing for gradations ensures the WF/CF stay within design limits to ensure the best product possible at point of delivery.
- QC Test at point of concrete placement allow real time data to be relayed to the batch plant operator for all necessary mix adjustments.
- QC Straight edge testing directly behind the paver while concrete is still plastic allows the paving crew to make critical edge slump adjustments. This is done to ensure all concrete meets tolerances before it has finished its hydration process.