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

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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 <u>many</u> benefits to both agency and contractor

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

This document includes information necessary for contractors to:

- understand common agency QC requirements,
- develop and implement the appropriate tools, processes, and procedures and 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.

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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

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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

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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
- *Water*
  - *Provisions for use of non-potable water source*
- *Provisions for recycled concrete aggregates, including those produced on-site, produced near-site, or sourced from a local producer*
- *Other information relevant to QC testing of specific materials*
- *Disposition of unsatisfactory materials*

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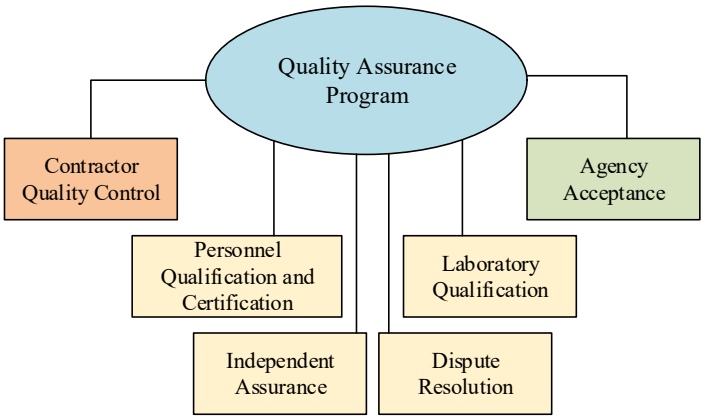
Section 1: Introduction

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



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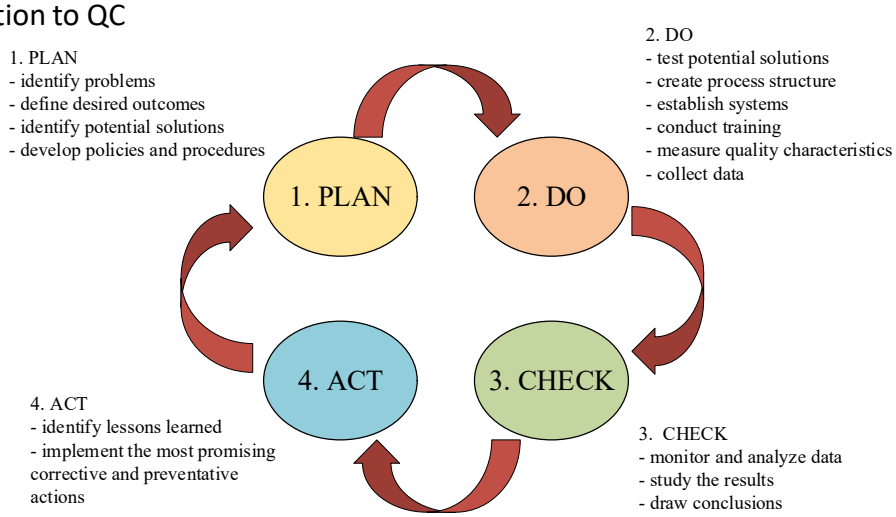
Section 2: Quality Control Fundamentals

- Introduction to QC



"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

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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:

- **Poor**: Aggregate stockpiles will be protected from runoff. Aggregates will be protected from the introduction of debris or other contaminants.
- **Fair**: Aggregate stockpiles will be protected from runoff using swales. Haul trucks will be unloaded adjacent to the stockpiles, and material will be placed on the stockpiles using other equipment. Contractor personnel will observe the stockpiles periodically to ensure contaminants have not been introduced to the material.
- **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

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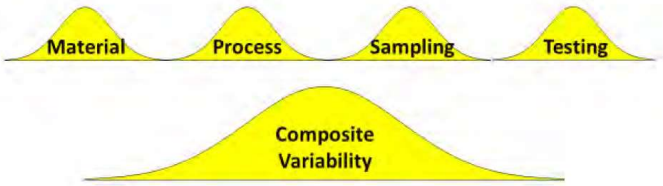
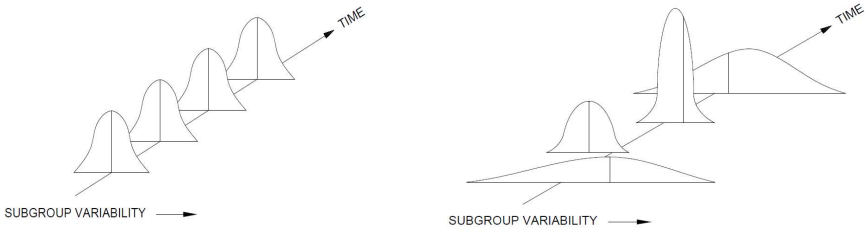
Section 2: Quality Control Fundamentals

- Understanding Variability
  - Sources of variability



  - Chance cause (natural) variability vs. assignable cause (not natural) variability



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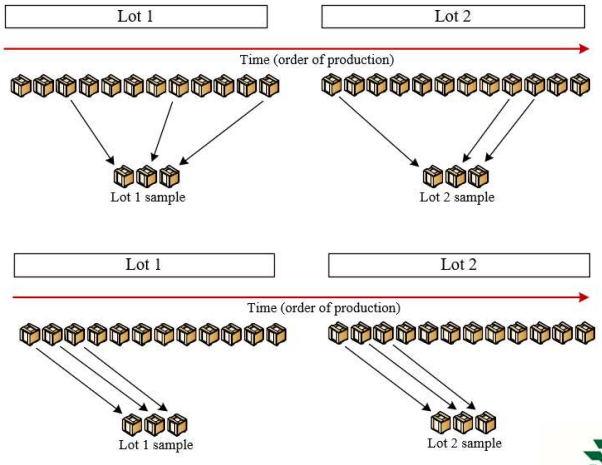
Section 2: Quality Control Fundamentals

- 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.

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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

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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 a material supplier's and/or contractor's approach to QC, it should not matter whether a pavement is constructed under PEM specifications or traditional concrete pavement specifications.

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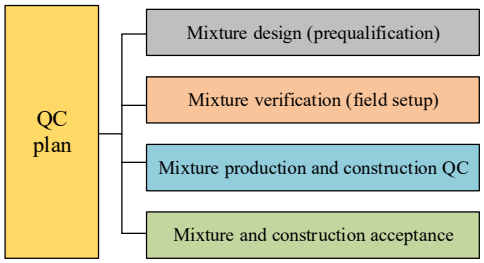
Section 5: QC for Concrete Pavement Construction

- Implementation of a QC Process



- 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)
Integrated Materials and Construction Practices Manual (Taylor et al. 2019)

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Section 5: Example Framework for Pavement Construction QC

Item	Mixture Design (prequalification)	Mixture Verification (field setup)	Mixture and Construction QC	Mixture and Construction Acceptance
QC Plan	✓	✓	✓	✓
Determination of Mixture Materials	✓			
Aggregate Grading	✓	✓	✓	✓
Mixture Proportioning	✓			
Temperature Sensitivity of Mixture	✓			
Mixture Properties (Example for PEM shown)	• As specified • Flexural strength at 3, 7, and 28 days • Compressive strength at 3, 7, and 28 days • Volume of paste • Restrained volume change at 180 days • *w/cm* • Unit weight • Fresh air content • Calcium oxychloride limit • Apparent F factor • Combined gradation • Modified VKelly Test	• As specified • Compressive strength at 3 and 7 days • Volume of paste • Restrained volume change at 7 days • *w/cm* • Fresh air content • Combined gradation • Modified VKelly Test	• As specified • Compressive strength at 3 and 7 days • Unit weight • Fresh air content • Combined gradation • Slump	• As specified • Compressive strength at 28 days • Fresh air content • Combined gradation
Pre-Paving Activities				
Subgrade			Perform QC measurements and develop checklists	
Subbase(s)				
Steel Placement				
Paver Controls				
Paving Equipment Setup				

Section 5: Example Framework for Pavement Construction QC

Item	Mixture Design (prequalification)	Mixture Verification (field setup)	Mixture and Construction QC	Mixture and Construction Acceptance
Mixture Production				
Stockpile Management			Perform QC measurements and develop checklists	
Plant Calibration		✓		
Transporting Concrete Mixture				
Mixture Adjustments		Appropriate adjustments include: • Subtraction/addition of water (not to exceed the w/cm of the approved mixture design) • Adjustment of admixture dosages • Minor reproportioning of aggregates • Heating or cooling the mixture	Appropriate adjustments include: • Subtraction/addition of water (not to exceed the w/cm of the approved mixture design) • Adjustment of admixture dosages • Minor reproportioning of aggregates • Heating or cooling the mixture	
Paving				
Spreading Concrete			Perform QC measurements and develop checklists	• Pavement thickness • Pavement smoothness
Fixed Form Placement				
Slipform Placement				
Hand Finishing				
Texturing				
Curing				
Sawing Joints				
Sealing Joints				
Backfill Pavement Edges				
Open to Construction Traffic				
Open to Public Traffic				

Section 5: QC Guidance for Each Step of Process

Staking and Stringline or Stringless QC

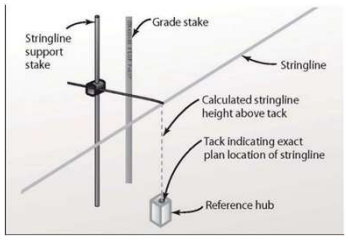
Key inspection items – Staking and stringline or stringless	**QC measurements** – Staking and stringline or stringless
• Spot check paving hubs and grades for accuracy by checking against a known benchmark. • Visually inspect stringline for abrupt changes and/or discontinuities (stringline only). • Check 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 survey check of paving hubs. • Random check of stringline elevation and alignment relative to paving hub information (not applicable to string which has been eyeball adjusted for smoothness) (stringline only).

Checklist – Staking and stringline

✓Verify the survey has provided the correct grades for 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.

Checklist – Stringless

✓Models (data) used for stringless machine control are prepared in accordance with the manufacturer's recommendations.
✓Stringless model is set to correct alignment and elevation and checked for accuracy.



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	**QC measurements** – Dowel baskets
• Check transverse spacing and offset from the edge of the pavement. • Bond breaker applied, if applicable. • Visually inspect for alignment – correct misaligned bars. • Verify that basket locations are marked on both sides of the pavement. • Baskets should be anchored so that the stake is on the downstream side of the basket frame. • Check the stability of the baskets – are they anchored adequately to withstand the force of a slipform paver pushing concrete over them?	• None during prepaving. • 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.

Checklist – Dowel baskets

✓ Correct dowel dimensions (diameter and length).
✓ Basket height is appropriate for the pavement thickness.
✓ Bar spacing is specified.
✓ Bar coating is as specified and not unduly damaged.
✓ Bond breaker is adequate.
✓ Verify that the dowel location is marked adequately on both sides of the slab to ensure proper joint sawing.

Dowel basket anchored to subgrade (upper) and existing asphalt (lower, both from Maria Masten, Minnesota DOT)

Section 5: QC Guidance for Each Step of Process

Mixture Production QC

Key inspection items – Mixture production	**QC measurements** – Mixture production
• 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.	• Sieve 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.

Checklist – Mixture production

- ✓ Batch proportions match the approved mixture design (daily).
- ✓ Moisture compensation is representative of the aggregates being batched (at least 2 times per day, more if necessary).
- ✓ Material inventories are adequate.
- ✓ Mixing drum is clean of dried materials which could break loose.
- ✓ Mixing blades are not overly worn.

Aggregate stockpiles (upper, from FHWA MCTC) and maturity testing (lower, from Lane Construction)

Section 5: Recommended laboratory tests for each stage

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

Concrete property	Test description	Test method	Comments
Workability	Aggregate gradation	ASTM C136 /AASHTO T 27 ASTM C566, AASHTO T 255	• Use the individual gradations and proportions to calculate the combined gradation
	Combined gradation	Tarantula curve	• Monitor uniformity
	Aggregate moisture content	ASTM C29	• Affects w/cm ratio and workability
	Slump	ASTM C143 / AASHTO T 119	• Indicates uniformity batch to batch
Air void system	Super Air Meter (SAM)	AASHTO TP 118	• Indicates uniformity batch to batch
Unit weight	Unit weight	ASTM C138 /AASHTO T 121	• Indicates uniformity batch to batch
Strength development	Compressive or flexural strength	ASTM C39 /AASHTO T 22 and/or ASTM C78 / AASHTO T 97	• Indicates uniformity batch to batch
	Maturity	ASTM C1074	• Opening times
Transport	Resistivity/F-Factor	Soak/store samples in salt solution	• Monitor over time • Indicates uniformity batch to batch
Other	Hydration	Semi-adiabatic calorimetry	• Indicates uniformity batch to batch

Section 5: Acceptance

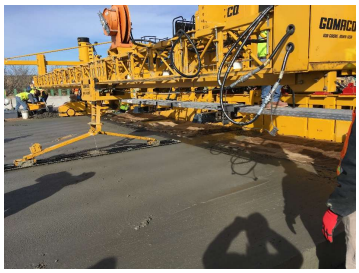
- Summary of acceptance tests (table shown below)

Property	Construction QC	Acceptance
	Test method / comments	Test method
Vibration monitoring	On board monitors • Monitor that all vibrators are operating • Ensure vibrator speed is appropriate for paver speed	On board monitors
Thickness	Probe behind paver	MIT-SCAN-T3
Smoothness	Real-time smoothness monitoring	Hardened smoothness – inertial profiler
Dowel alignment	MIT-DOWEL-SCAN	MIT-DOWEL-SCAN

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

Appendix C: QC Plan Outline

- QC plans reviewed from several contractors
- QC Plan Outline is <u>generic</u>
  - 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



- Narrative describing the process
- QC measurements
  - Frequency
  - Locations
  - Action limits
  - Suspension limits
- Checklist items
- Visual inspection items
- Corrective actions

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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

- NETTCP Template/Framework Used
- Some text provided to aid in developing content and specific QC provisions
- Sample tables provided

* Information in RED should be developed or modified to meet the agency requirements and contractor preferences. Other text can also be modified as appropriate.

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.

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Appendix D: Model QC Plan

4.0 MATERIALS CONTROL

4.1 Materials Suppliers

The following material suppliers will be providing materials for the concrete pavement. All material suppliers will be responsible for testing and inspection to verify materials meet the appropriate specifications prior to delivery to the project.

Material	Type/Brand	Supplier	Source
Cement	Type I/II	Rock Solid Cement	Limestone, USA
Fly Ash	Class F	Mid-Central Fly Ash Supply	Bituminous, USA
Coarse/Intermediate Aggregate	No. 57/No. 89	Rocky Aggregate Company	Metamorphic, USA
Fine Aggregate	C33 natural sand	Sandy Banks Company	Siliceous, USA
Admixtures	Air entraining admixture/Bubbleair 9000, Mid-range water reducer/Slumpy 750	Chemical Admixture Company	Synthetic, USA
* Modify table as appropriate.			

4.2 Applicable Specifications and Standards

* Describe specifications and standards applicable to each material. Provide information detailing how materials will meet each specification and standard either at the producer/supplier or upon delivery to the project site.

4.3 Plant Layout and Materials Delivery/Storage

* Describe plant layout, including delivery/haul routes, drainage provisions, storage areas and storage facilities.

4.3.1. Cementitious materials

* Provide information on delivery and storage of cementitious materials.

4.3.2. Aggregates

* Provide information on delivery and storage of aggregates. Provide details on stockpile management and means to protect stockpiles from contamination. Describe the stabilized foundation used beneath stockpiles and how moisture variability will be controlled. Also describe plant loading procedures.

5.0 QUALITY CONTROL SAMPLING AND TESTING

The requirements and procedures to be used for QC sampling and testing of concrete, materials used to produce concrete, and concrete pavement are shown below.

5.1 Lot and Sublot Sizes

Each Lot of material will represent material from the same source, be produced or obtained under the same controlled process, and will possess normally distributed specification properties. Each Lot will be divided into Sublots of equal size in order to assess the quality characteristics of the Lot. The Lot size and corresponding sublot size for each item is identified in the following table.

* Modify table to include items, materials, lot sizes, and sublot sizes as appropriate.

Item	Material type(s)	Lot size	Sublot size
Aggregates	Coarse aggregate	300 CY	60 CY
	Intermediate aggregate	300 CY	60 CY
	Fine aggregate	300 CY	60 CY
Concrete	Fresh concrete	5,000 SY	1,000 SY
	Hardened concrete	300 CY	See testing table below
	Concrete pavement	5,000 SY	1,000 SY
* Modify table as appropriate.			

5.2 Random Sampling Plan

* Modify description of random sampling plan as appropriate. Provide documents related to random sampling in Appendix.

PCC Paving Contractors will establish a random sampling plan for QC sampling and test for each lot of material prior to placement of the lot. All samples will be obtained randomly in accordance with ASTM D3665. The random sample location for each Sublot will be determined by station, offset, and depth within the sublot.

All random sample locations will be documented on standard test report form D3665. A copy of the random sampling forms is located in Appendix B. PCC Paving Contractors will provide the State Transportation Agency a copy of the random sampling locations (a completed form D3665) for each placement, during the start of the placement each day.

5.3 Sample Identification System

* Modify sample identification system as appropriate.

All material samples will be clearly identified as follows:

Example Sampling and Testing Table

Material	Test/Test Method	Lot Size	No. of Sublots	Testing Frequency	Sampling Location	Sampling Method	Report Type
Coarse and fine aggregates	• Gradation - ASTM C136	5,000 SY	5	1 per sublot and/or minimum 1 per day	Stockpile	Random, per agency specification	Tabular and graphical: % retained, Tarantula
Fresh concrete	• Air content - ASTM C231	5,000 SY	5	First 3 loads per day and repeat for 3 loads whenever admixture dosages are adjusted	1. Plant 2. Grade 3. Behind paver	Biased, start of day	Tabular and control chart
	• SAM - AASHTO T 152 • VKelly - AASHTO TP 129	N/A	5	First 3 loads per day and repeat for 3 loads whenever admixtu	Plant	Biased,	Tabular and rol chart
Fresh concrete at grade	• Temperature - ASTM C1064 • Air content - ASTM C231 • Air void system – AASHTO T 152 • Unit weight - ASTM C138 • Water content - AASHTO T 318	5,000 SY	5	1 per sublot			ular and rol chart
Hardened concrete	• Compressive strength - ASTM C39 Resistivity - AASHTO T 358	5,000 SY	5	One set of three re minimum set of th			ular and rol chart
Concrete pavement	• Thickness probe, per agency spec	5,000 SY	5	1 per sublot			ular and rol chart
	• Maturity - ASTM C1074	5,000 SY	5	1 per sublot	Grade	Random	Tabular and control chart
	• Thickness - ASTM C174 • Thickness MIT-SCAN-T3	5,000 SY	5	1 per sublot	Pavement cores	Random	Tabular and control chart
	• Dowels MIT-DOWEL-SCAN	N/A	N/A	All dowelled joints	All dowelled joints	N/A	N/A

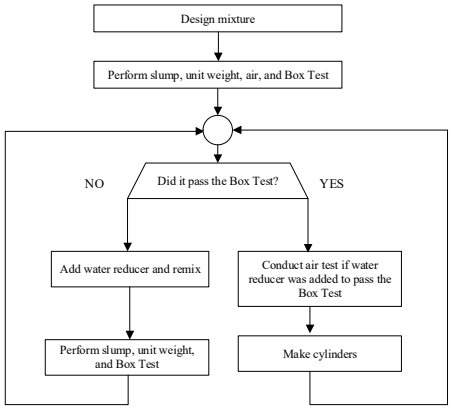
Example lot sizes, sublots, and sampling and testing frequencies from several states specifications are provided

Section 6: Tools for QC

What gets measured gets managed...

This section provides information on tools that can be used to help record, process, and use measurements to support decision making and continuous improvement.

- 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



Flowchart for Box Test (from Cook et al. 2013)

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

Worked example run/control charts for:

- single measurements
- two measurements

- 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

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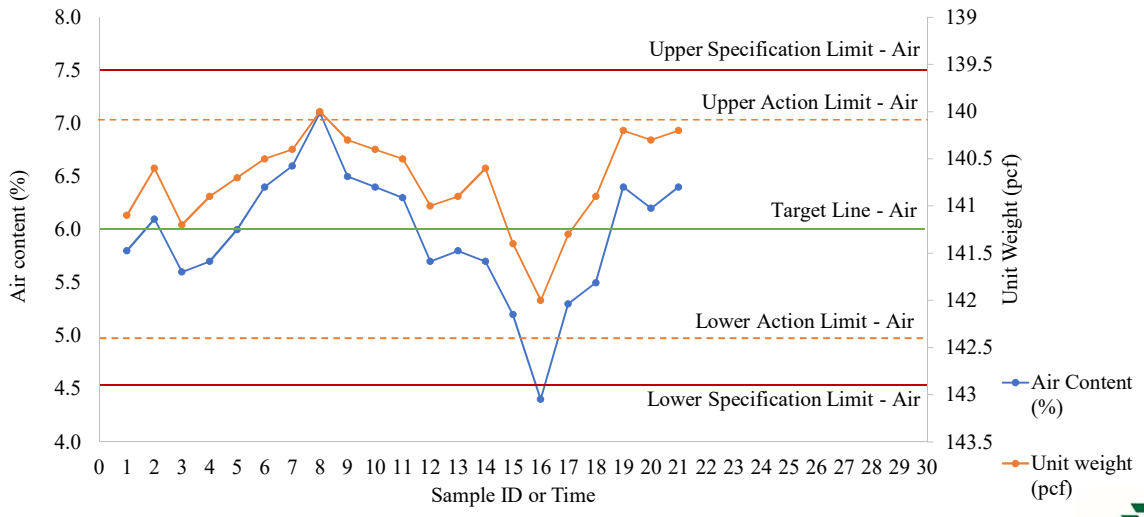
Section 6: Run Charts and Control Charts – Guidance for Development and Use



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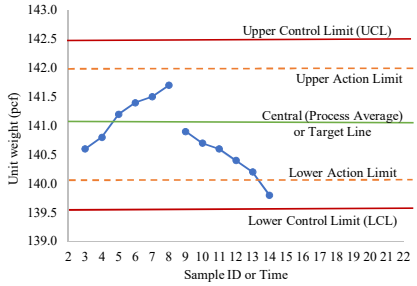
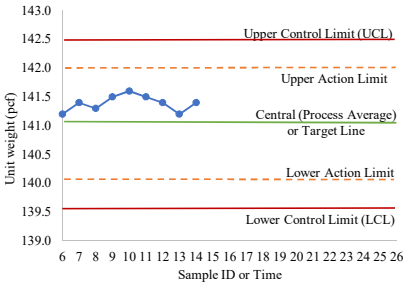
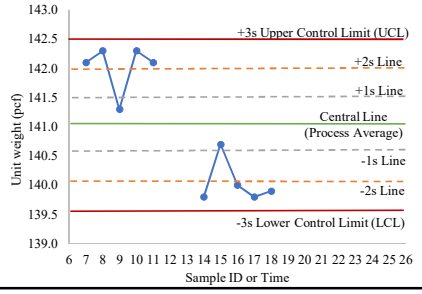
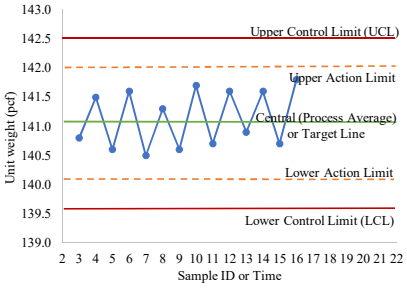
Section 6: Control Charts – Trends that suggest assignable cause variability









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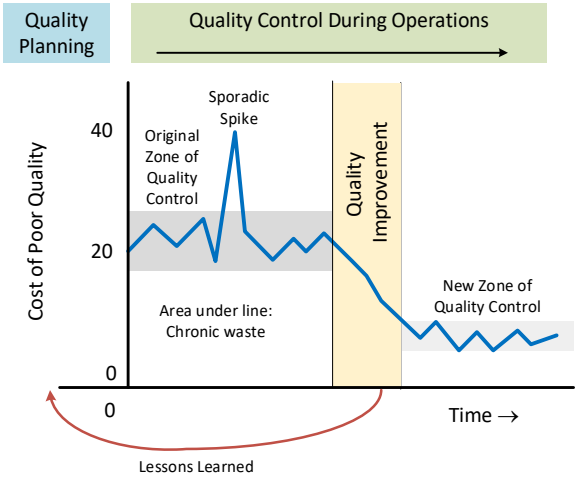
Closing

- 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



Adapted from Juran

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