Best Practices for Concrete Pavement Construction QC

Tara Cavalline, PhD, PE (UNC Charlotte)

Sarah Dalton, P.E. (ACPA)

May 20th 2025

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About the Presenter

- **Tara Cavalline** is a Professor in the William States Lee College of Engineering at UNC Charlotte.
- Her research interests are concrete and cementitious materials, quality management, use of recycled materials in concrete, and asset management.
- Tara has 25 years of engineering experience, 6 as a consulting engineer in Charlotte, NC and over 18 in academia at UNC Charlotte.
- Background in concrete materials, sustainability, quality assurance
- Projects on concrete pavements and structures for NCDOT, others
- FHWA Cooperative Agreement team with National Concrete Pavement Technology Center at Iowa State University

About the Presenters

- Senior Director of Construction and Engineering for ACPA
- Worked 5 years with CO/WY Chapter ACPA prior to joining ACPA National
- Started her career as a Quality Control Manager for a concrete paving contractor
- Holds a Bachelor of Science degree in Civil Engineering from the University of Colorado, Graduate certificate in Pavement Engineering from the University of Illinois and is a registered professional engineer
- Focus is providing technical assistance and education related to specifications, design, construction, and rehabilitation of concrete pavements

Today's Learning Objectives

- Learn the benefits that both agencies and contractors can achieve through comprehensive, effective QC.
- Identify the key components of a QC Plan.
- Identify resources available to help develop and implement the appropriate processes and procedures to meet agency QC requirements.
- Identify common challenges affecting materials, mixtures, and pavement quality , and describe tools and guidance for mitigating these issues.

Questions?

- Questions are encouraged. Please enter your questions (and answers) in the question box and we will share the Q & A electronically following the webinar.

- PDH certificates will be sent to participants electronically.
- Presentations and recordings will be posted on the CP Tech Website.

www.cptechcenter.org/webinars-and-videos/

Upcoming Webinar Schedule
Concrete Pavement Technology Tuesday

FAA's Concrete Airfield Pavement Advancements

Tuesday, June 17th
12:00 pm CDT

Gary Mitchell – ACPA
Jeff Crislip - FAA

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https://www.acpa.org/webinars/

Best Practices for Concrete Pavement Construction and QC

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Best Practices for Concrete Pavement Construction QC and Process Control

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American Concrete Pavement Association
Tara L. Cavalline, PhD, PE
University of North Carolina at Charlotte

Iowa State University
Institute for Transportation

National Concrete Pavement Technology Center
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Benefits of QC for Agencies

- Improved quality of construction as contractors enhance their QC plans
- Increased confidence in the use of contractor QC data as part of the agency's acceptance decision
- Confidence to consider loosening or removing restrictive prescriptive specifications
- Confidence to consider implementing performance-type specifications

Benefits of QC for Contractors

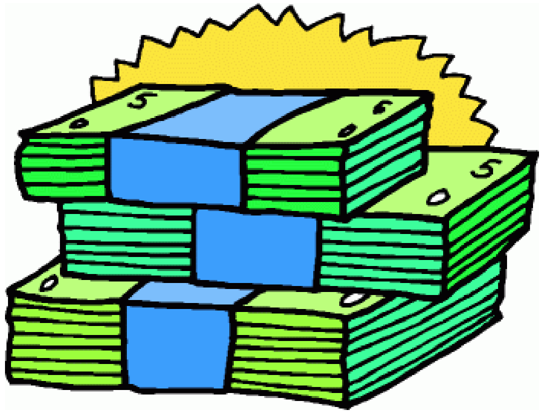
- QC is important to the success of a company
- Good QC:
  - Increases profitability
  - Lowers risk
  - Improves reputation

- Money invested in QC activities regularly provides benefits far exceeding the amount invested.

QC – Important for Contractors!

- Contractors maintain autonomy and responsibility for their production and processes.

- QC includes sampling and testing by contractors so they can:
  - understand and control their processes
  - reduce variability,
  - manage risk,
  - improve reputation, and
  - improve quality of their work

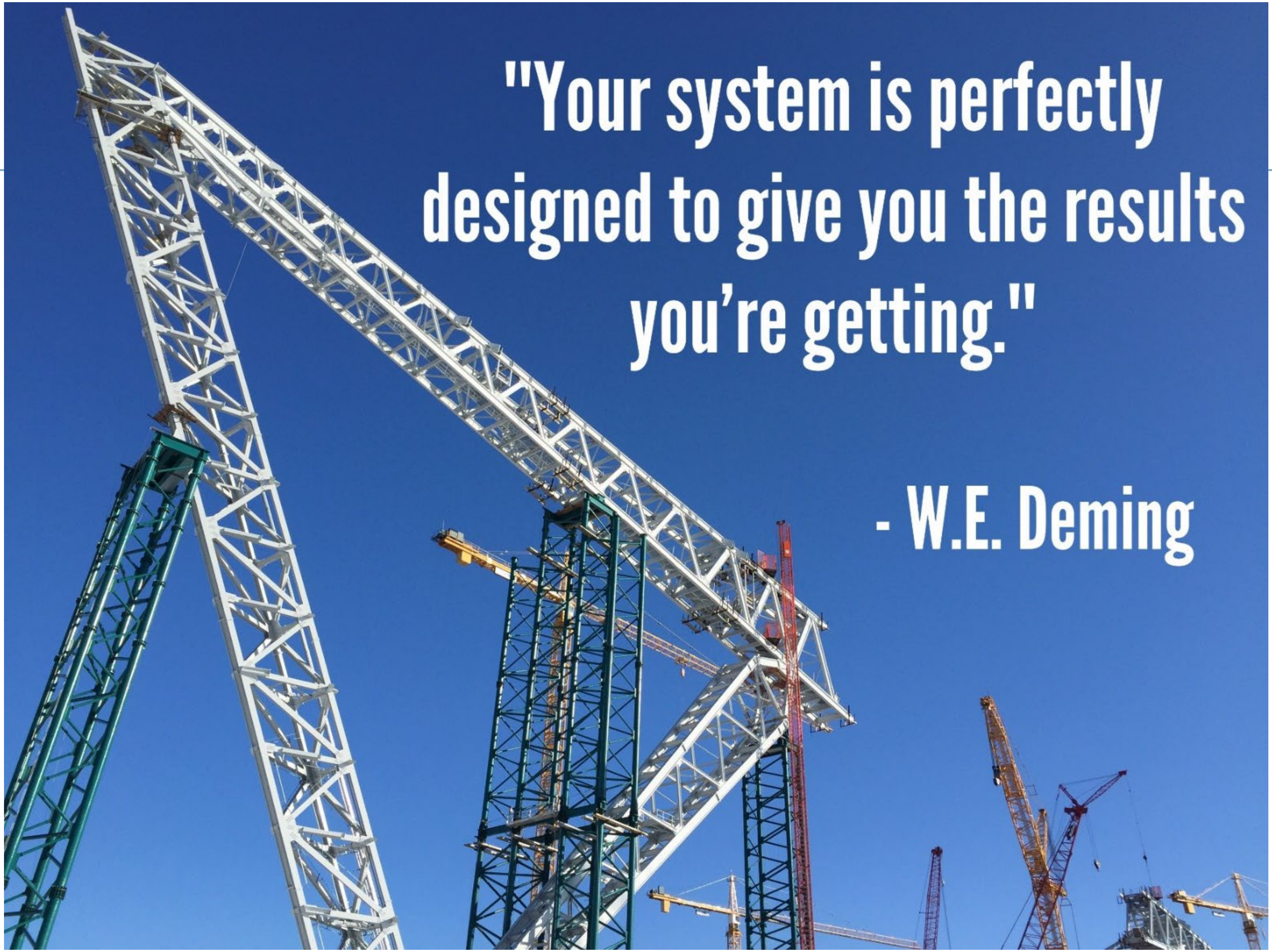


Benefits of Quality Management Systems

- QC Manager for a concrete supply company
  - Applying for a group insurance policy
  - Audit discovered 80% of workplace injuries occurred during rework
  - Invested in QC improvement, reduced workplace injuries
  - Saved money on insurance premium (and in other ways)

- Cement supplier
  - Many instances where data from QC program prevented them from becoming involved in construction lawsuits

> "Facts are stubborn things, as they do not change. As such, facts (data) from your quality program can save a lot of potential issues and grief."



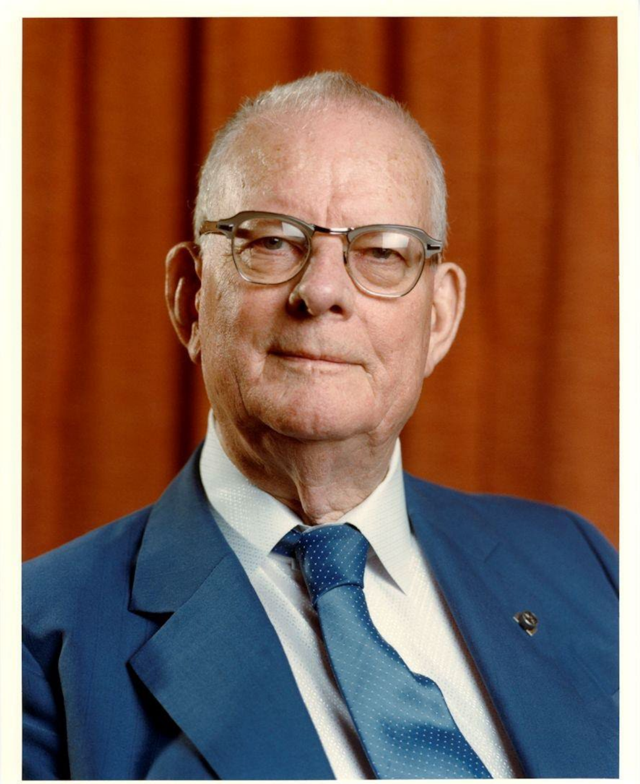


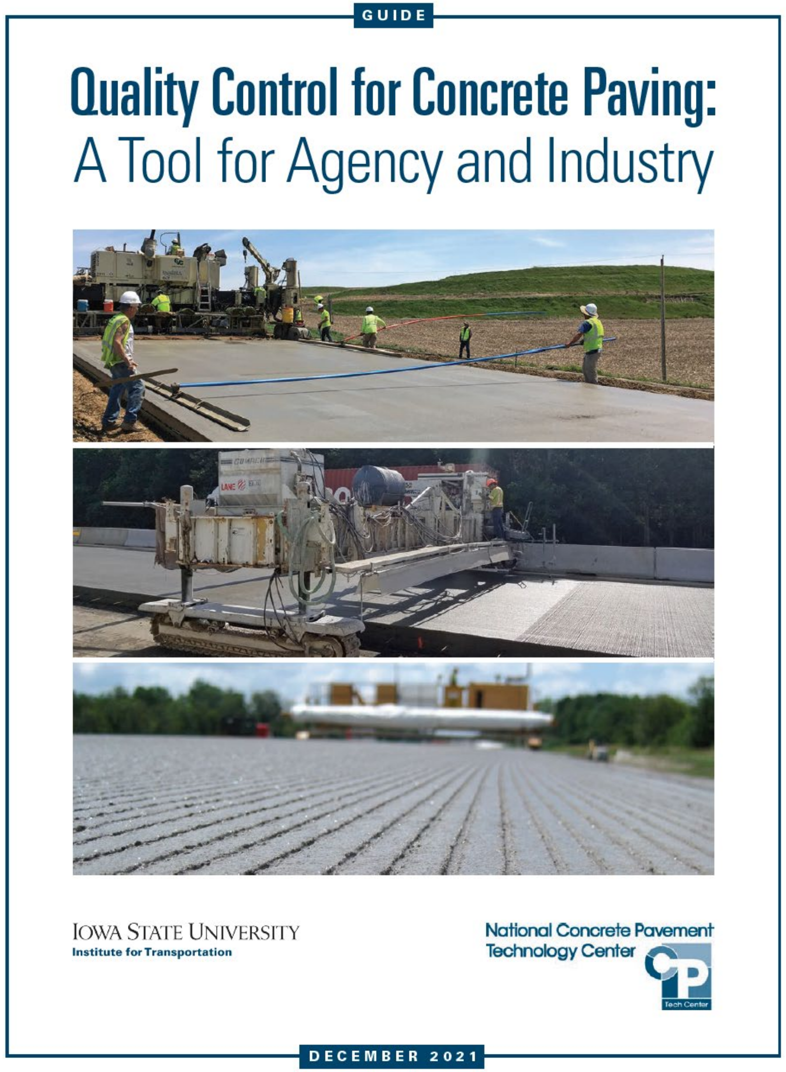
Image credits: Oshatrain

QC for Concrete Paving: A Tool for Agency and Industry

- Free download
- Tech Briefs summarizing different sections are forthcoming

Gary Fick, Transtec

Al Innis, Consultant



Overview of QC Guide

- Ch. 1: Introduction
- Ch. 2: Quality Control Fundamentals
- Ch. 3: Quality Control for Materials Suppliers
- Ch. 4: Performance Engineered Concrete Mixtures
- Ch. 5: Quality Control for Concrete Pavement Construction
- Ch. 6: Tools for Quality Control

Overview of QC Guide

- Appendices:
  - A: Common Agency QC Requirements
  - B: Example QC Plan Provisions
  - C: QC Plan Outline
  - D: Model QC Plan
  - E: Control Charts – Additional Statistical Examples

QA Program Definitions

Elements of a QA Program 23 CFR 47 and TRB Glossary - TRB E-circular E-C235 (2018)

Glossary of Transportation Construction Quality Assurance Terms

- QC Program
- QC Plan
- QC Process

Process control vs. QC

Figure: Dennis Dvorak, FHWA

Comprehensive Approach to QC

- Successful QC and process control require:

  1) QC programs that operate continuously “behind the scenes.”
     - Trained personnel
     - Appropriate materials
     - Reliable equipment

  2) Effective, project-specific QC Plans

  3) Personnel that understand how to implement the QC Plan and use information obtained to support adjustments and obtain the desired result

Comprehensive Approach to QC

- Effective QC goes beyond material sampling and testing at the specified frequencies
- Must establish methods, practices, and measurements for all embedded processes
  - These must enable adjustments to the materials and processes in a timely manner
- Personnel must be able to obtain useful data AND know what to do with that information

Culture of Quality

- Quality must be a focus of all personnel involved in each step of the construction process
- Fostering a culture of quality from the top-down is important to ensure buy-in of personnel
  - Respect, effective communication, freedom to speak up without fear of retribution
- Essential components of QC and process control
  - Understanding and implementing the plan
  - Documentation
  - Communication
  - Continuous improvement

QC Programs

- Procedures and practices that occur continuously within the organization
- Support process control and QC plans required for each project
  - 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, recordkeeping, control of documents

QC Plan

Objective of QC Plan:

to establish a framework of activities and actions that, when implemented over the course of a <u>project</u>, 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

"Boilerplate" QC plans offer no assurance that a quality project will be delivered

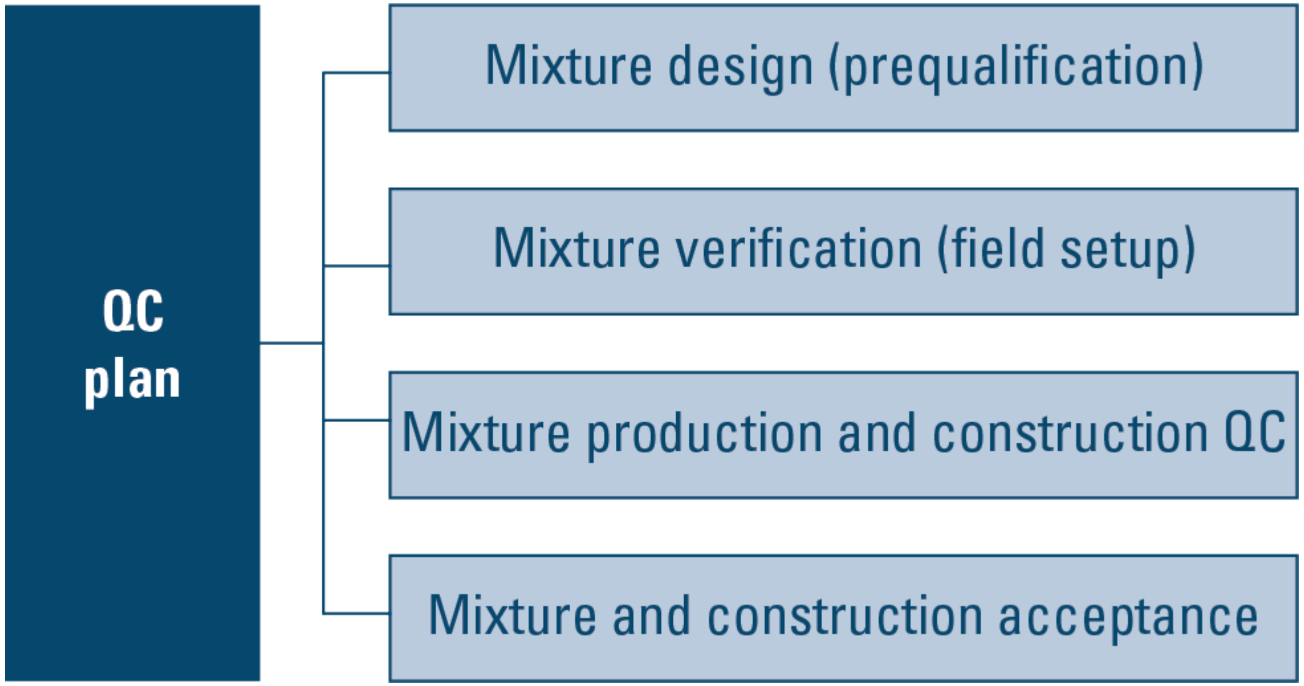
QC Plans Will Differ Based On:

1. The components of the project for which the agency requires a QC plan
2. The components of the project for which the prime contractor or subcontractors deem a QC plan to be necessary or desirable
3. Relationships between the prime contractor, subcontractor, and materials suppliers
4. The project delivery method

Typical Elements of a QC Plan

- 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
  - Issues warranting correction/adjustment, suspension, or rework
- Documentation required

Four Stages to Consider in QC Plan



- In a QC plan, the contractor should describe the actions that will be performed to control the process.
- During construction, these actions should then be performed.
- In other words, “Say what you do and then do what you say.”

Appendix C of Guide: QC Plan Outline

- General topics and framework
  - Developed from review of several contractors' QC plans
- Outline is generic
- Should be tailored to each project
  - Consider specifications
  - Project conditions
  - Construction approaches
- If you have a QC plan template or approach that works, perhaps this can provide some items that could be added or approached differently

From Transtec

Appendix D of Guide: Model QC Plan

- Heavily based on the Typical Model Quality Control Plan prepared by the NorthEast Transportation Training and Certification Program (NETTCP)
- www.nettcp.com
- 10 sections plus Appendices
    - 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

From Transtec

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.

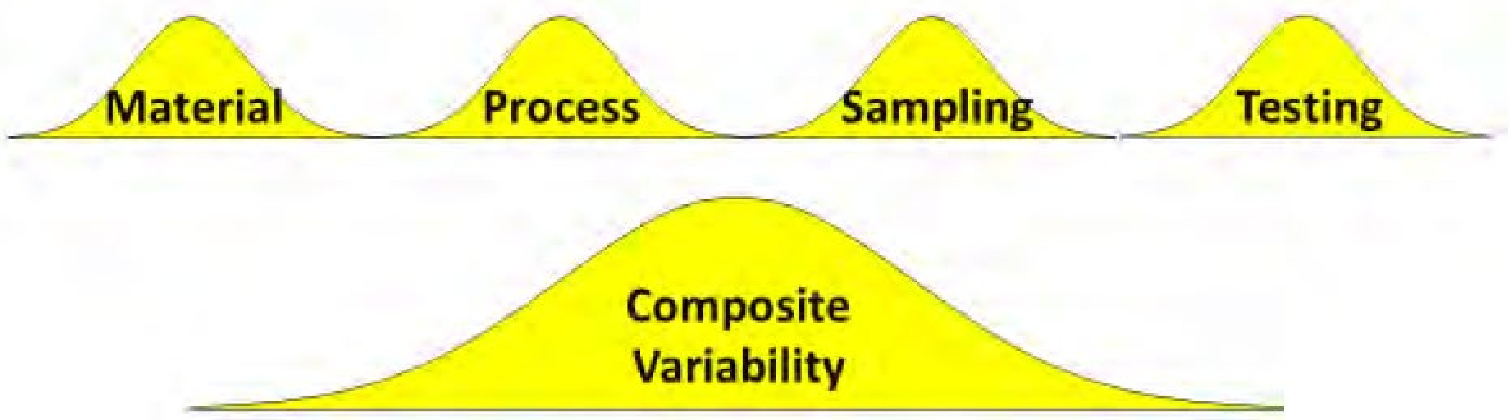
All random sample locations will be documented on standard test report form D3665. A copy of the random sampling forms is located in Appendix B. PCC Paving Contractors will provide the State Transportation Agency a copy of the random sampling locations (a completed form D3665) for each placement, during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

Sources of Variability

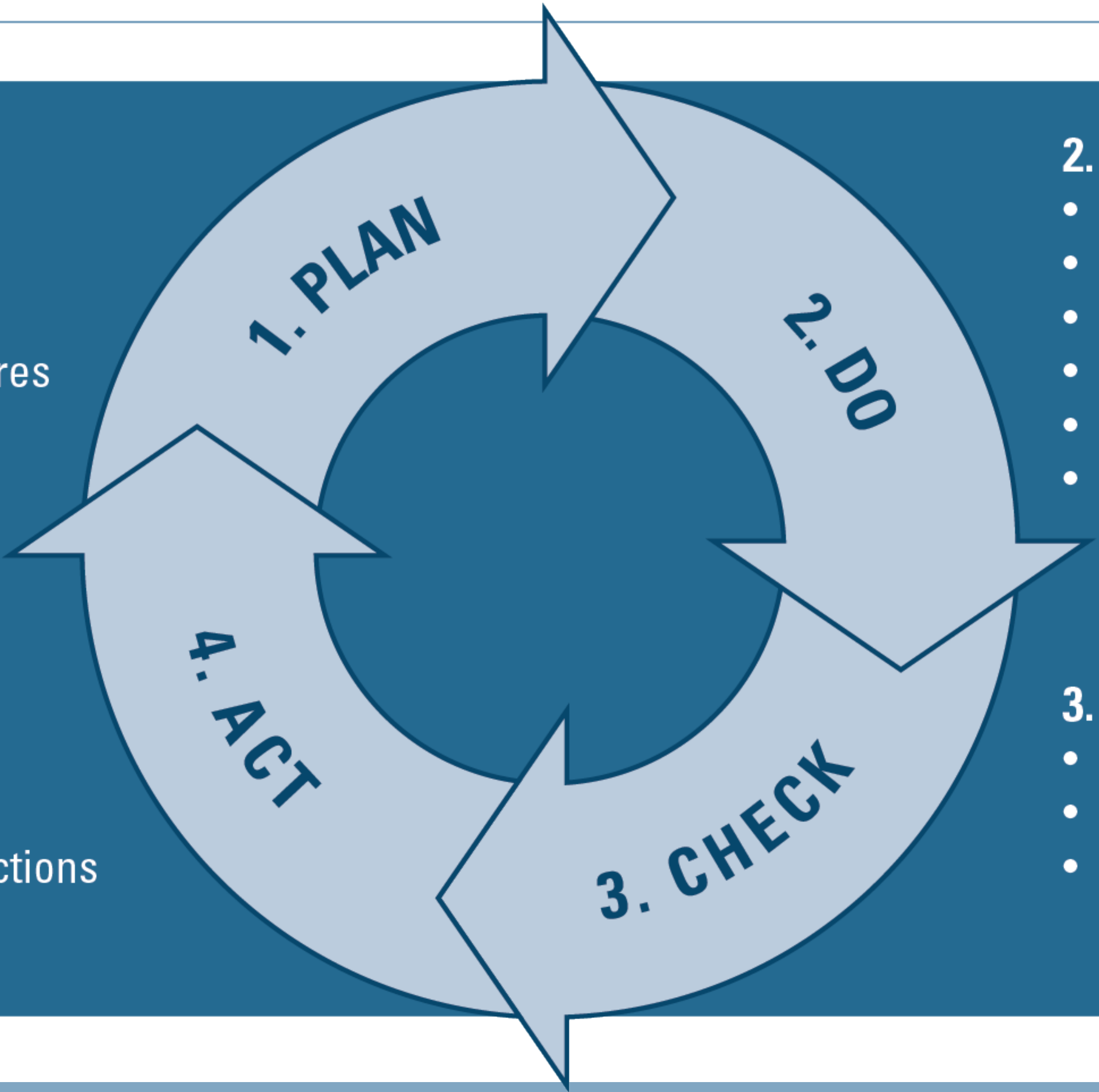


- **Material variability** is a function of variations in the raw materials, including their composition and properties such as strength, ductility, porosity, moisture content, and many other natural characteristics or characteristics imparted by the production process.
- **Process variability** is the result of variation induced by equipment, operators, or the environment.
- **Sampling variability** and **testing variability** are the result of many types of environmental-, human- and equipment-related factors.

Plan-Do-Check-Act Cycle (Deming Cycle)

1. PLAN
- Identify problems
- Define desired outcomes
- Identify potential solutions
- Develop policies and procedures

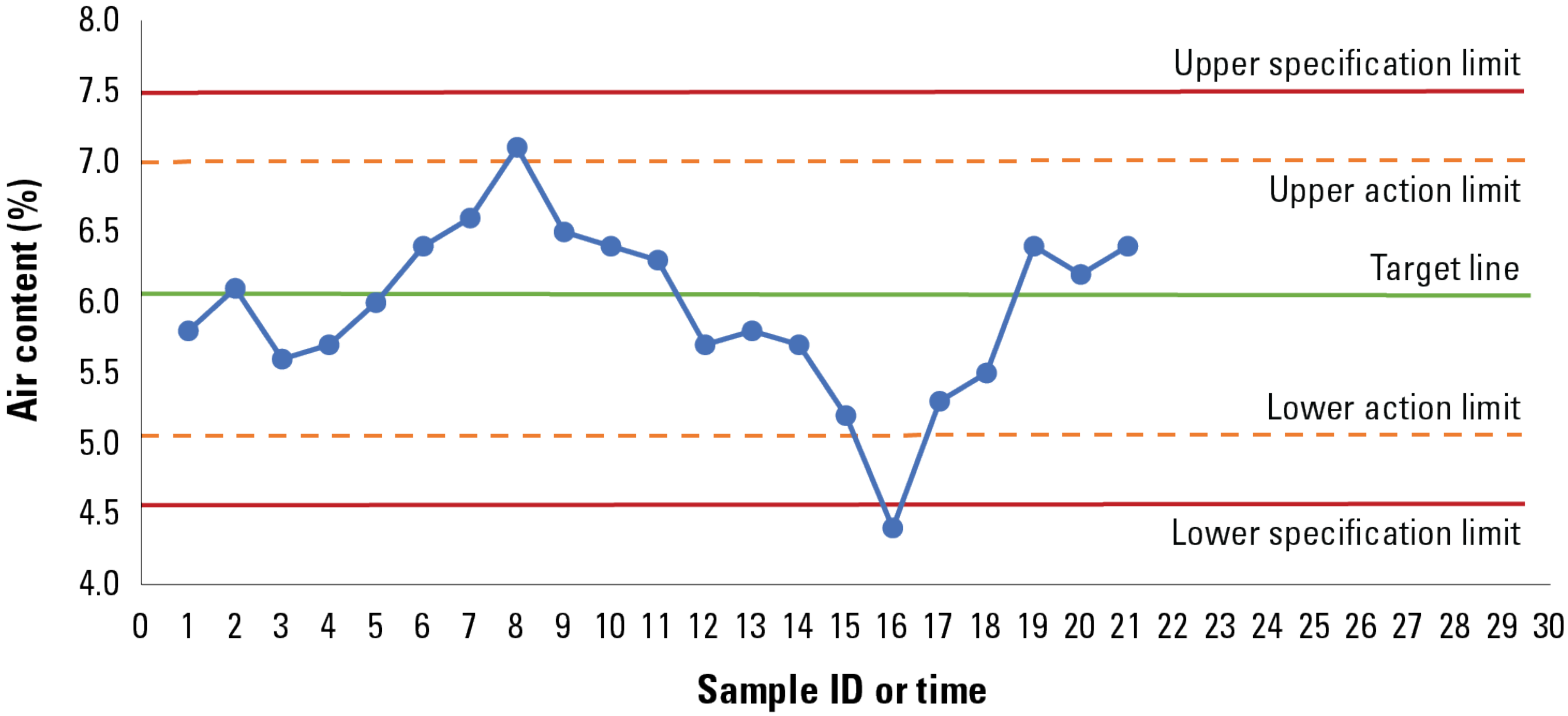
2. DO
- Test potential solutions
- Create process structure
- Establish systems
- Conduct training
- Measure quality characteristics
- Collect data



4. ACT
- Identify lessons learned
- Implement the most promising corrective and preventative actions

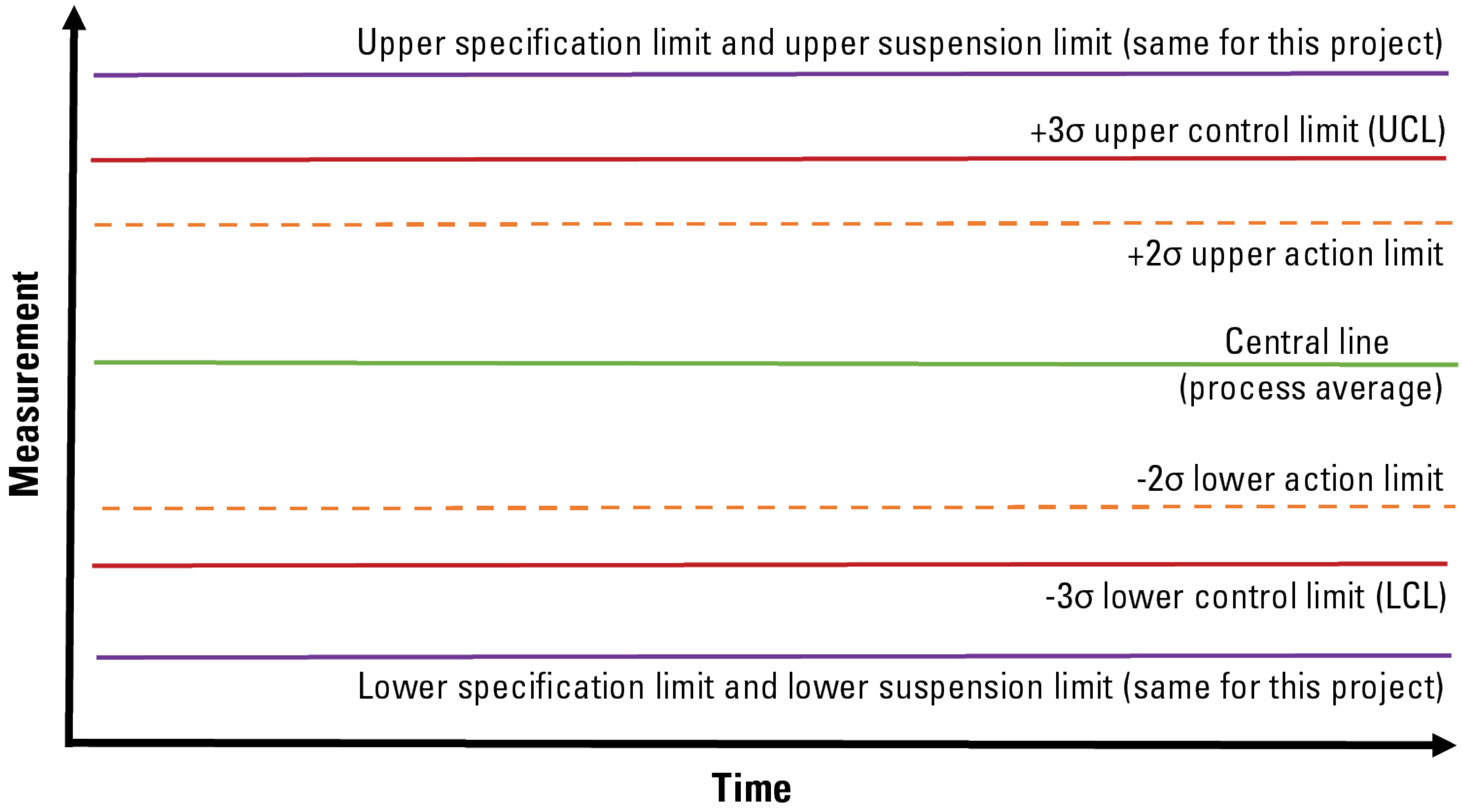
3. CHECK
- Monitor and analyze data
- Study the results
- Draw conclusions

Run Chart Example



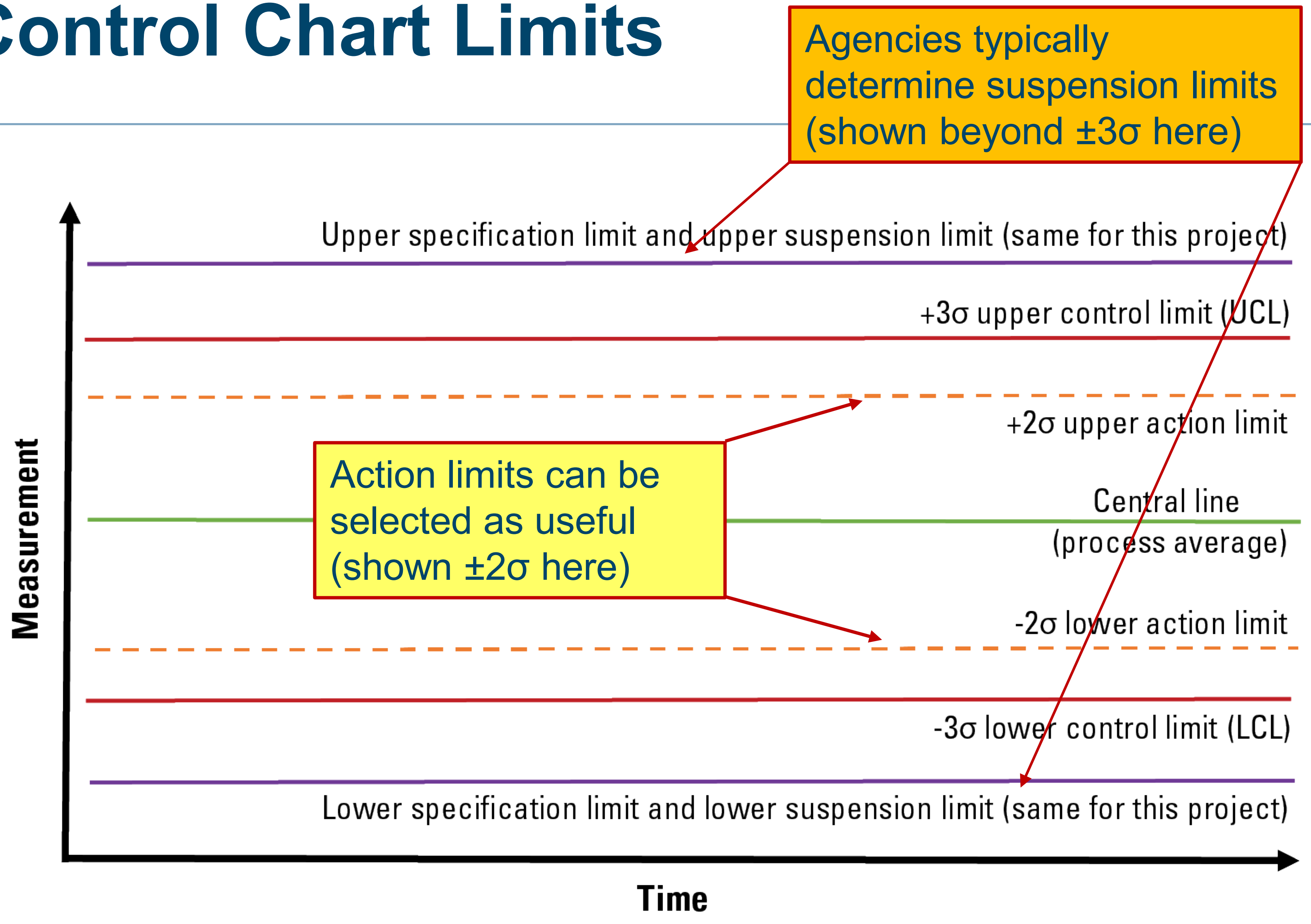
Constructing a Control Chart

- Sample IDs or sampling times shown on x-axis
- Measurement shown on y-axis
- Central line is measure of central tendency (moving average)
- Limit lines are plotted based on standard deviation of the data



Control Chart Limits

- Measurements exhibiting natural (chance cause) variation will most likely be within ±3σ of the average measurements
- If data is normally distributed and exhibiting natural variation only, 99.73% should fall within ±3σ
- Data points outside of ±3σ likely due to an assignable cause (issue)

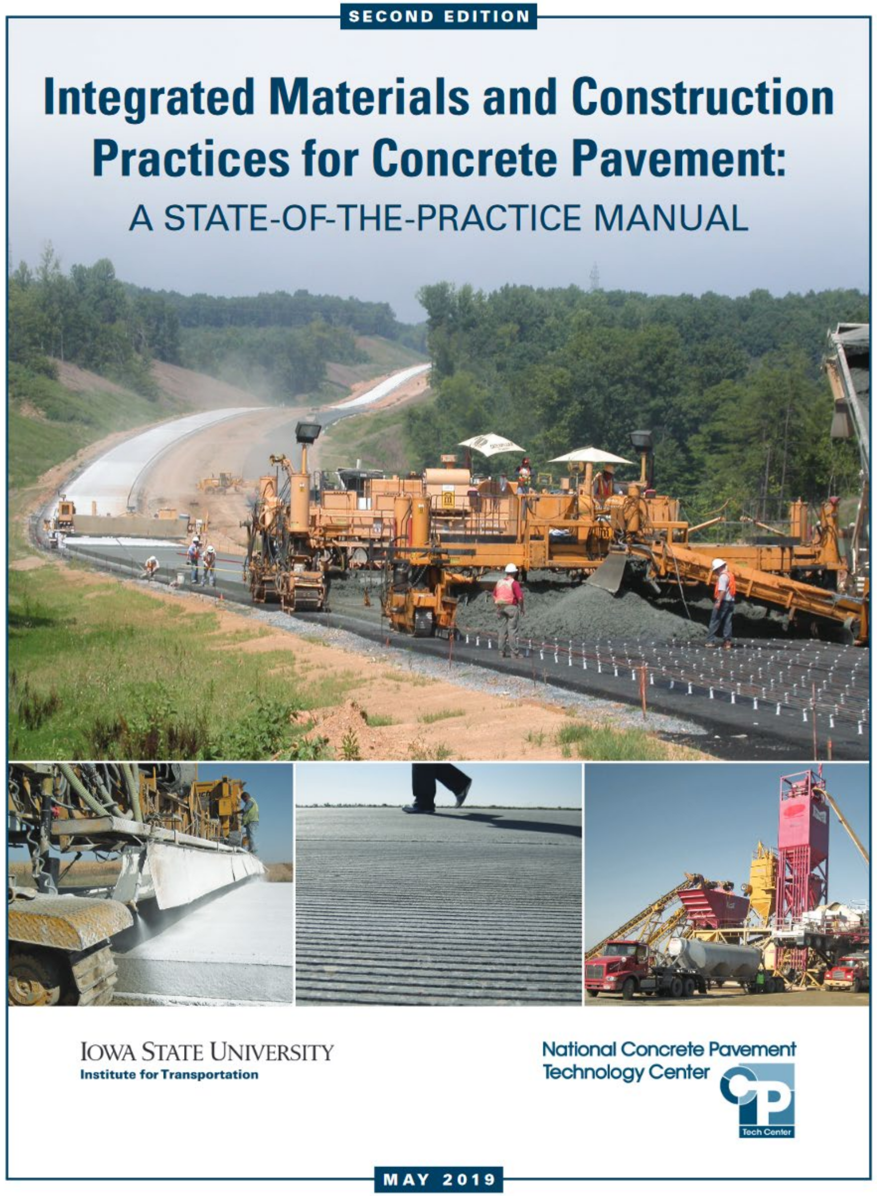


Key resources

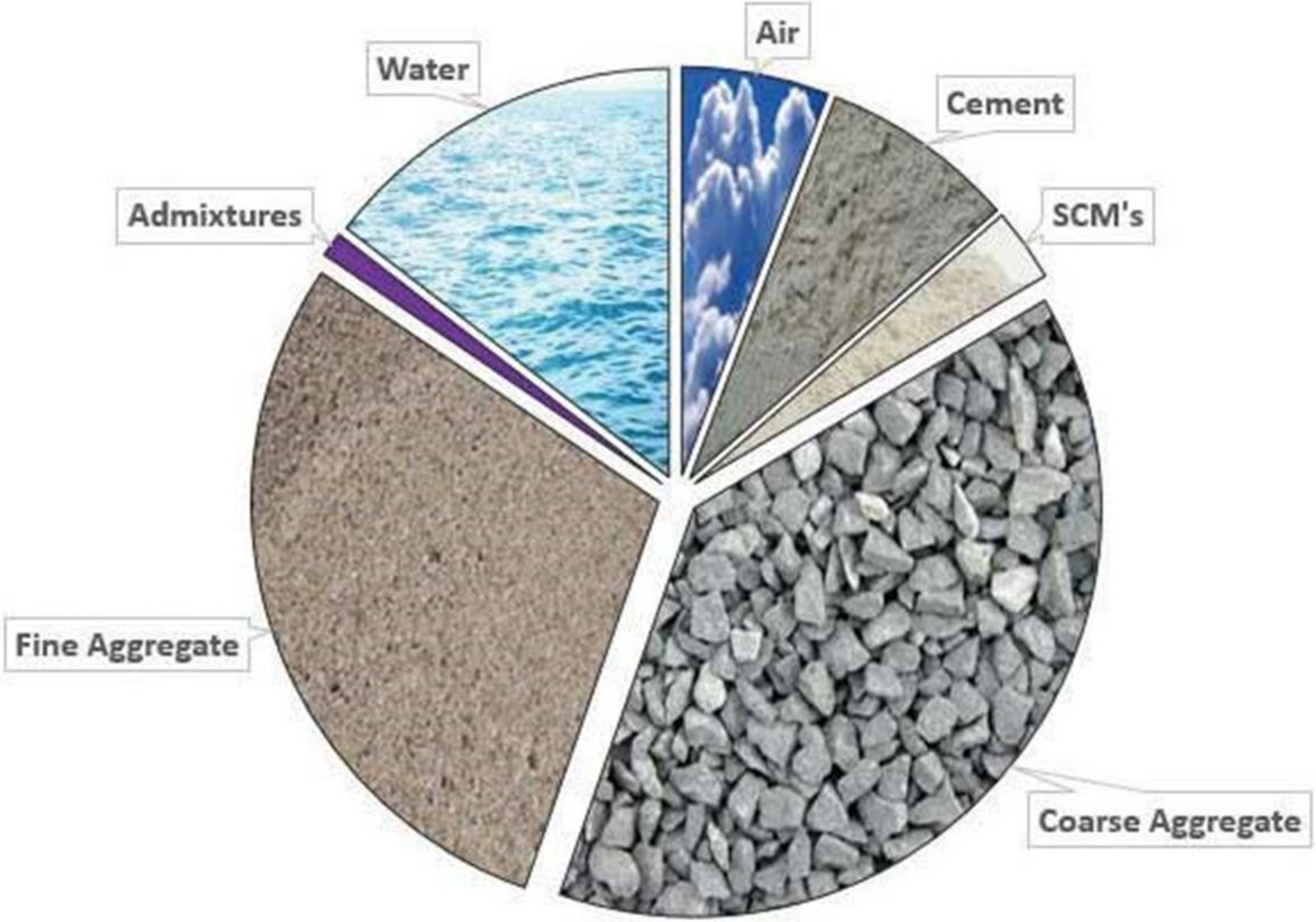
- National Highway Institute (NHI) Course Number 131141, *Quality Assurance for Highway Construction Projects* (NHI 2020)

- *Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual* (Taylor et al. 2019)

- *Field Reference Manual for Quality Concrete Pavements* (Fick et al. 2012)



Mix Design and Construction Best Practices



A good mix starts with proper specifications

- Cement Type
- Aggregate Size
- Strength
- Air Content

- Understanding local materials
  - Aggregate quality/types
  - Cement types
  - SCM availability

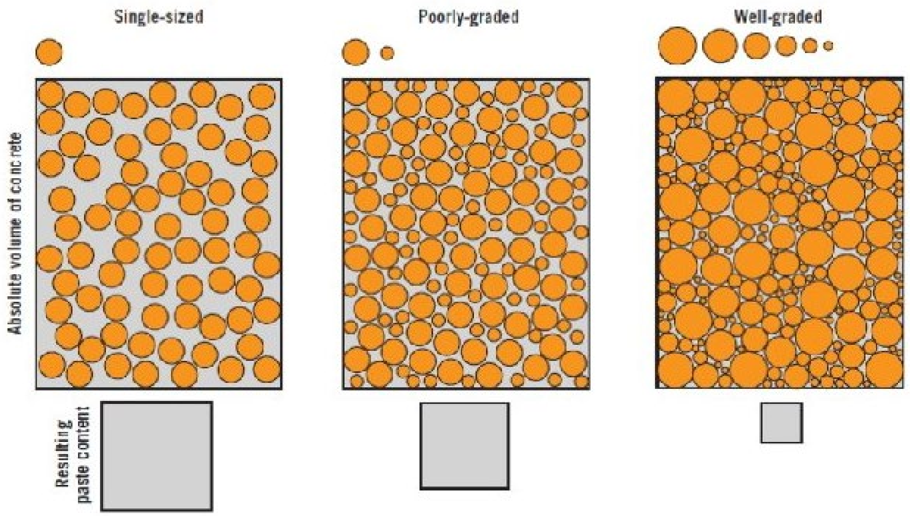
Just because it meets the spec… doesn't make it a good mix

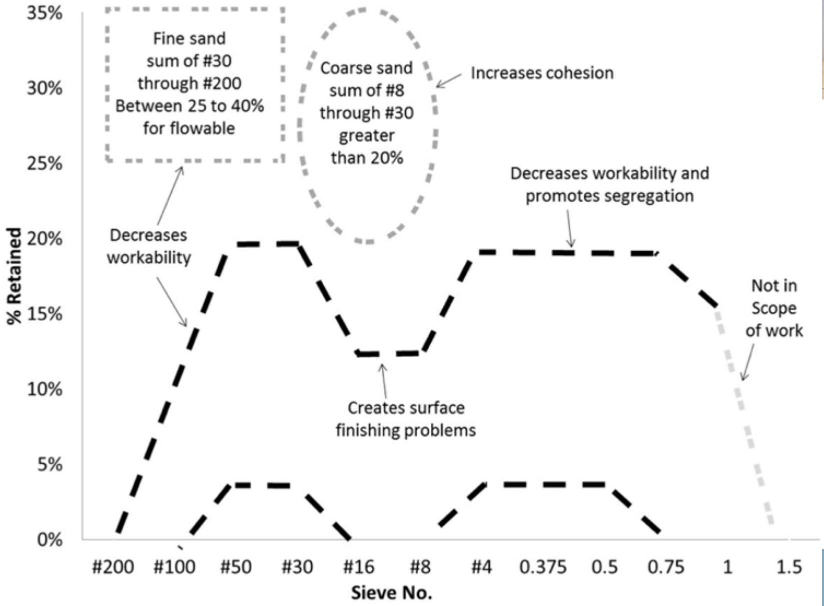
Aggregates

- Aggregates comprise the majority of the volume of a concrete mix
  - 60% to 75% of the volume of concrete
  - Want to have inert and dimensionally stable
- Aggregate properties strongly influence
  - Workability
    - Gradation
    - Shape
  - Durability of the pavement
    - Aggregate quality
  - Strength
    - Aggregate cleanliness

Optimized Combined Gradations

- What will it do for me?
- Less paste=> Lower permeability
- Less paste=> Reduced thermal shrinkage
- Less paste=> Reduced drying shrinkage
- Less paste=> Improve durability
- Less paste=> Improve Sustainability
- Less paste=> Improve Strength



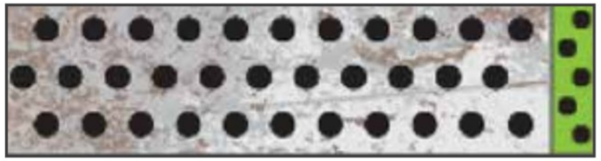


Portland Limestone Cement

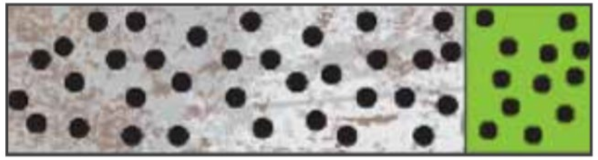
plc portland-limestone cement

- Producing PLC reduces amount of cement clinker needed per ton
  - Reduces carbon footprint of cement/concrete
  - Reduces amount of energy required per ton of cement
- Designed to perform SIMILAR TO Ordinary Portland Cement (OPC)
  - Water demand may be slightly higher due to fineness
  - Early strengths may be different
  - Set time should be equal
  - Know your supplier

Portland cement can contain up to 5% limestone along with the clinker



Portland limestone cement can contain from 5% to 15% limestone along with the clinker.

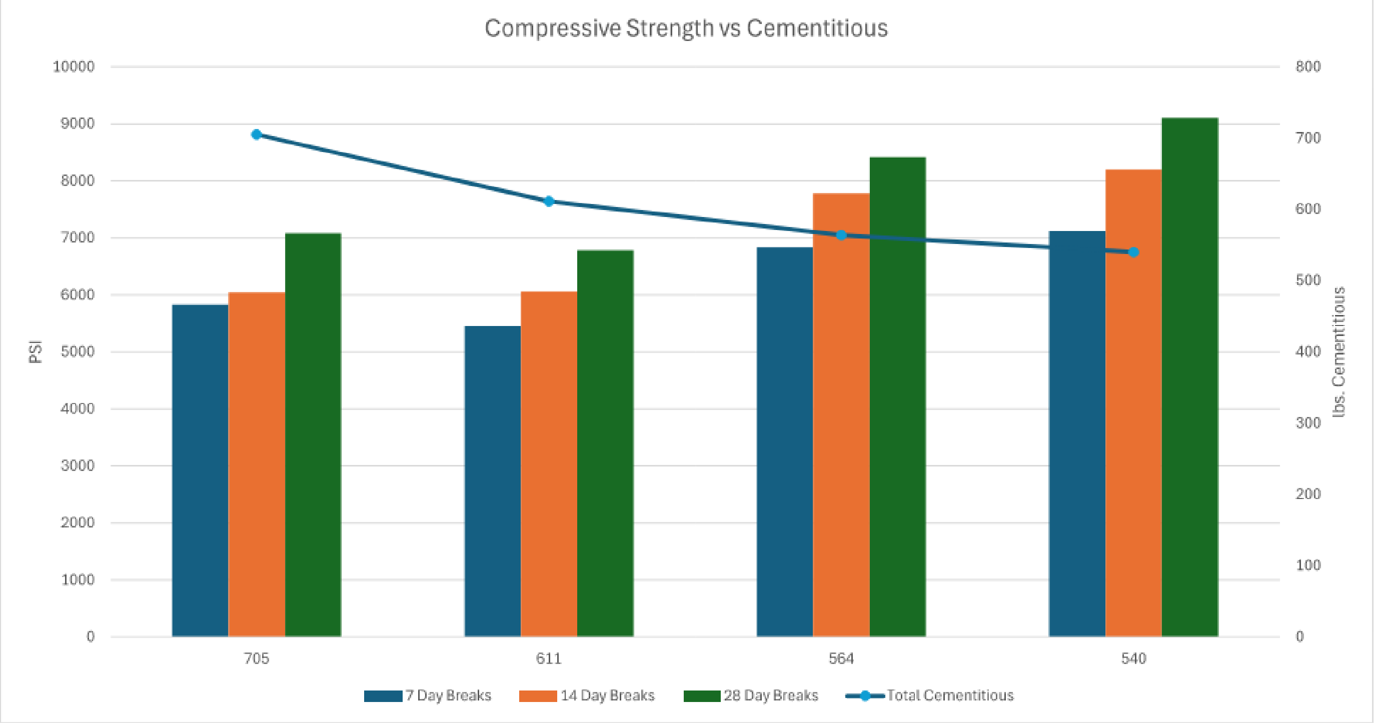


More information: https://greenercement.com/

Cement Content

- Excess has a negative effect on:
  - Permeability
  - Shrinkage
  - Cost
  - Strength
- Optimum depends on:
  - Aggregate type
  - Gradation
  - Aggregate shape
- Performance Specs do not specify minimum or maximum cement contents

Sack	Total Cementitious	Cement	Class N	#4 Rock	#57 Rock	#89 Rock	Sand	W/CM	Gallons	7 Day Breaks	14 Day Breaks	28 Day Breaks
7.5	705	564	141	550	825	275	1100	0.40	34.17	5830	6040	7080
6.5	611	489	122	587	881	294	1174	0.40	29.38	5450	6060	6780
6	564	452	112	604	906	302	1208	0.40	27.34	6840	7780	8420
5.74	540	432	108	615	923	308	1230	0.40	25.78	7120	8200	9100



Supplementary Cementitious Materials

Effects of SCMs on Fresh Concrete Properties

	Fly ash				Natural pozzolans		
	Class F	Class C	Slag cement	Silica fume	Calcined shale	Calcined clay	Metakaolin
Water demand	↓	↓	↓	↑	↔	↔	↑
Workability	↑	↑	↑	↓	↑	↑	↓
Bleeding and segregation	↓	↓	↕	↓	↔	↔	↓
Setting time	↑	↕	↑	↔	↔	↔	↔
Air content	↓	↓	↔	↓	↔	↔	↓
Heat of hydration	↓	↕	↓	↔	↓	↓	↔

Effect depends on material composition, dosage, and other mixture parameters

Key:
- ↓ lowers
- ↑ increases
- ↕ may increase or lower
- ↔ no impact

Source: Kosmatka and Wilson 2016, PCA

Supplementary cementitious materials (SCMs) from left to right: Class C fly ash, metakaolin (calcined clay), silica fume, class F fly ash, slag cement, and calcined shale

Source: Portland Cement Association

Effects of SCMs on Hardened Concrete Properties

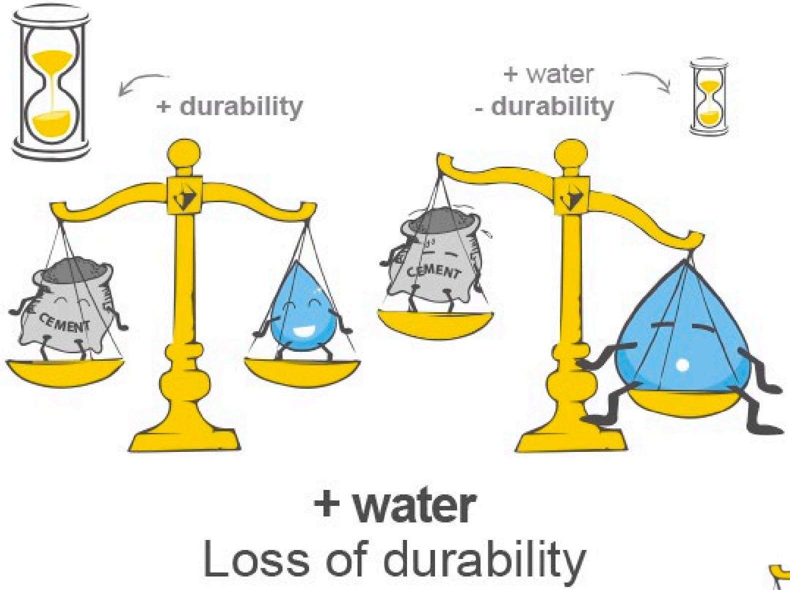
	Fly ash				Natural pozzolans		
	Class F	Class C	Slag cement	Silica fume	Calcined shale	Calcined clay	Metakaolin
Early age strength gain	↓	↔	↕	↑	↓	↓	↑
Long term strength gain	↑	↑	↑	↑	↑	↑	↑
Abrasion resistance	↔	↔	↔	↔	↔	↔	↔
Drying shrinkage and creep	↔	↔	↔	↔	↔	↔	↔
Permeability and absorption	↓	↓	↓	↓	↓	↓	↓
Corrosion resistance	↑	↑	↑	↑	↑	↑	↑
Alkali-silica reactivity	↓	↓	↓	↓	↓	↓	↓
Sulfate resistance	↑	↕	↑	↑	↑	↑	↑
Freezing and thawing	↔	↔	↔	↔	↔	↔	↔
Deicer scaling resistance	↔↓	↔↓	↔↓	↔↓	↔↓	↔↓	↔↓

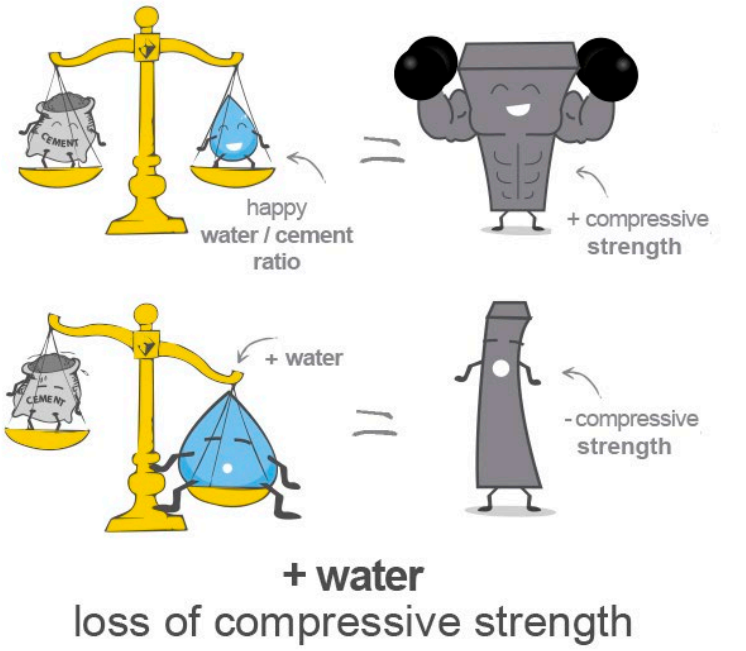
Effect depends on material composition, dosage, and other mixture parameters; these general trends may not apply to all materials and therefore testing should be performed to verify the impact.

Key:
- ↓ lowers
- ↑ increases
- ↕ may increase or lower
- ↔ no impact
- ↔↓ may lower or have no impact

Source: Kosmatka and Wilson 2016, PCA

Water/Cementitous Ratio





- Generally 0.38 - 0.42
- May go to 0.45 in specific cases
- Higher W/Cm ratio negatively impacts strength and durability
- Use enough water for hydration
- How accurate is your data?

Images from putzmeister.com

Concrete Materials Admixtures

- Air entraining admixtures (AEA)
- Water reducers
- Set modifying admixtures
  - Retarders
  - Accelerators
  - Hydration Stabilizers

To make good concrete better, not to fix bad concrete

The Box Test

- This test is should be performed on all mix designs.
- This test will tell you how the mix will respond to your paver.
- How well will the mix close up holes
- How well will the mix hold an edge

Admixture Incompatibilities

- Mix Designs should include water reducer effectiveness testing.
- What are the physical properties 30 to 45 minutes after batching?
- The water reducer can have a very large impact in the mix.

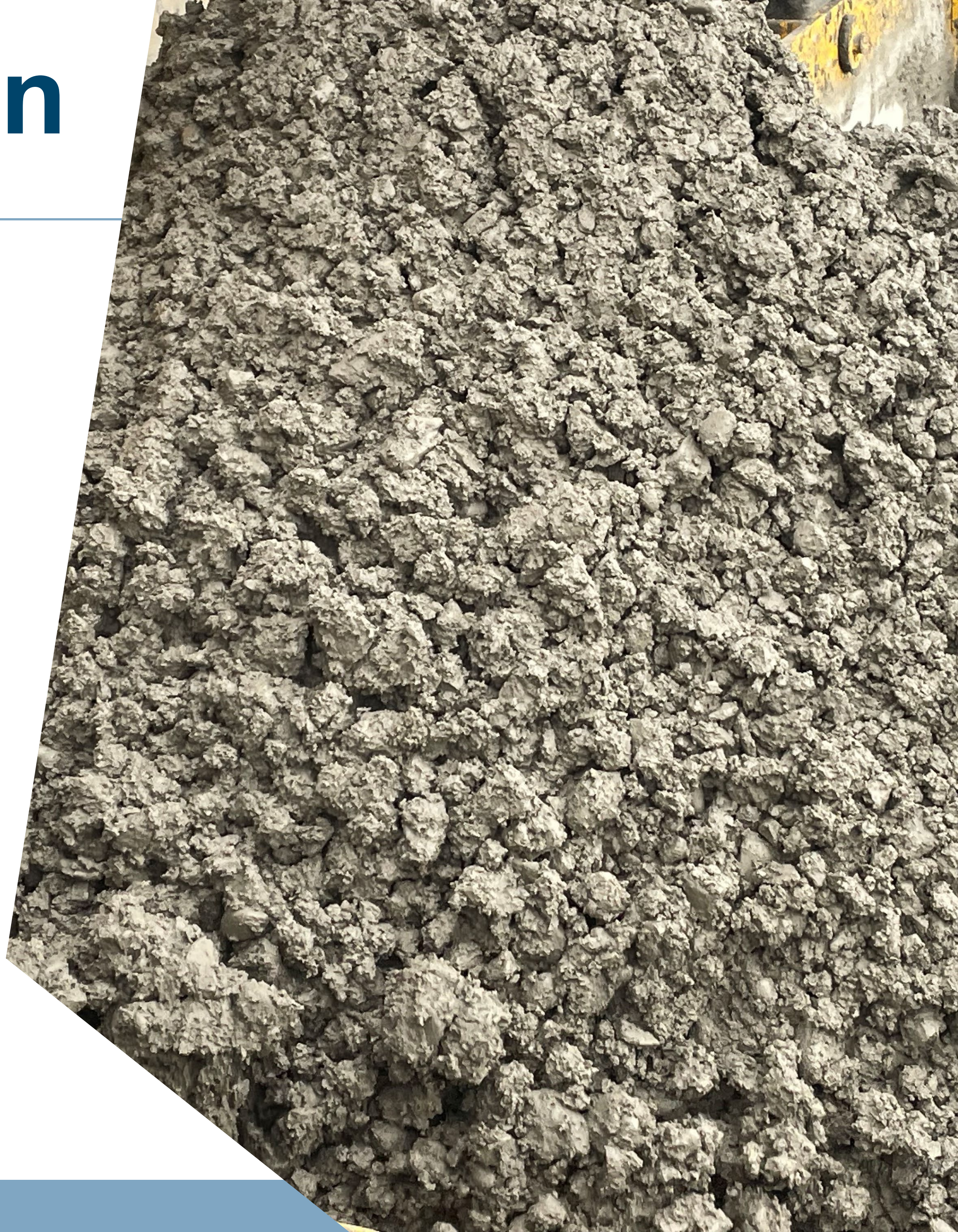
Photo courtesy of Matt Fonte

- Mix Designs should include water reducer effectiveness testing.
- The water reducer can have a very large impact in the mix.
- 60 ounces of fluid made the difference in this mix.

Photo courtesy of Matt Fonte

Concrete Mix Design

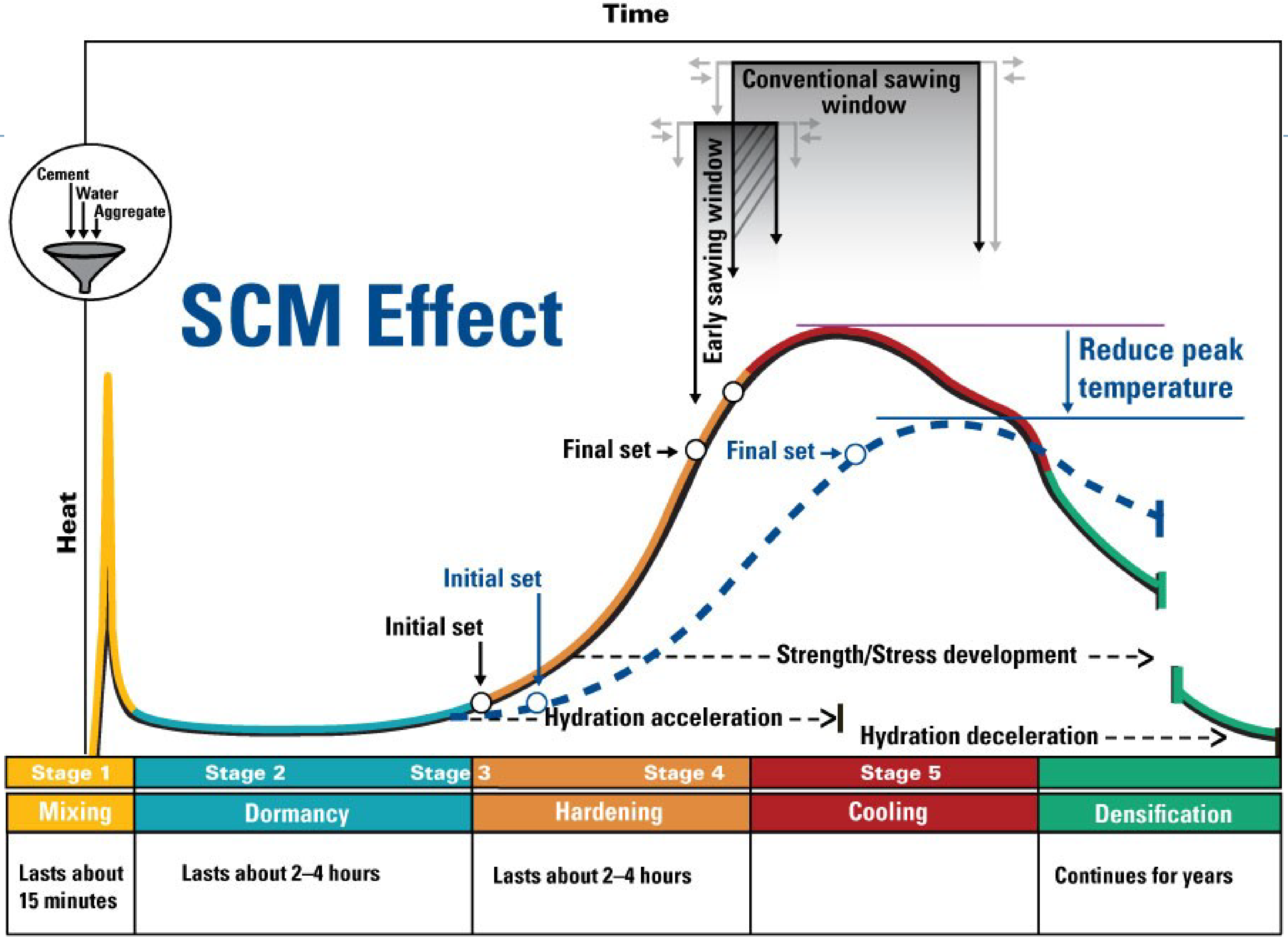
- Workability is dependent on the aggregate gradations.
- Paste content effects durability
- Testing for the effectiveness of the water reducers
- Not all admixtures are compatible with all Cements &SCM's
- Testing a range of water cement ratios and aggregate combinations at mix design time.



Placing and Finishing

Vibration

- Reduction in energy
- Lower the better
- Relationship between consistent grout box and vibration
- Dynamite effect
- Vibrators create pressure under the pan



Time
Conventional sawing window
Early sawing window
Cement
Water
Aggregate
SCM Effect
Reduce peak temperature
Final set
Final set
Initial set
Initial set
Heat
Strength/Stress development
Hydration acceleration
Hydration deceleration
Stage 1
Stage 2
Stage 3
Stage 4
Stage 5
Mixing
Dormancy
Hardening
Cooling
Densification
Lasts about 15 minutes
Lasts about 2–4 hours
Lasts about 2–4 hours
Continues for years

Finishing – Burlap Drag

- Wetting of the burlap
  - Uniform
  - Light application
  - Intermittent Spray

Finishing – How Much is Enough

- Two operations
  - Straight edge
    - Correct Bumps and Dips
  - Float
    - Filling Voids
    - Avoid Over finishing

Finishing – Adding Water to the Surface

- "Blessing" the slab
- Adding water to the surface

Finishing – Excessive Water

- How does the QC plan address hot windy days?
- Evaporation Retarders are not finishing aids

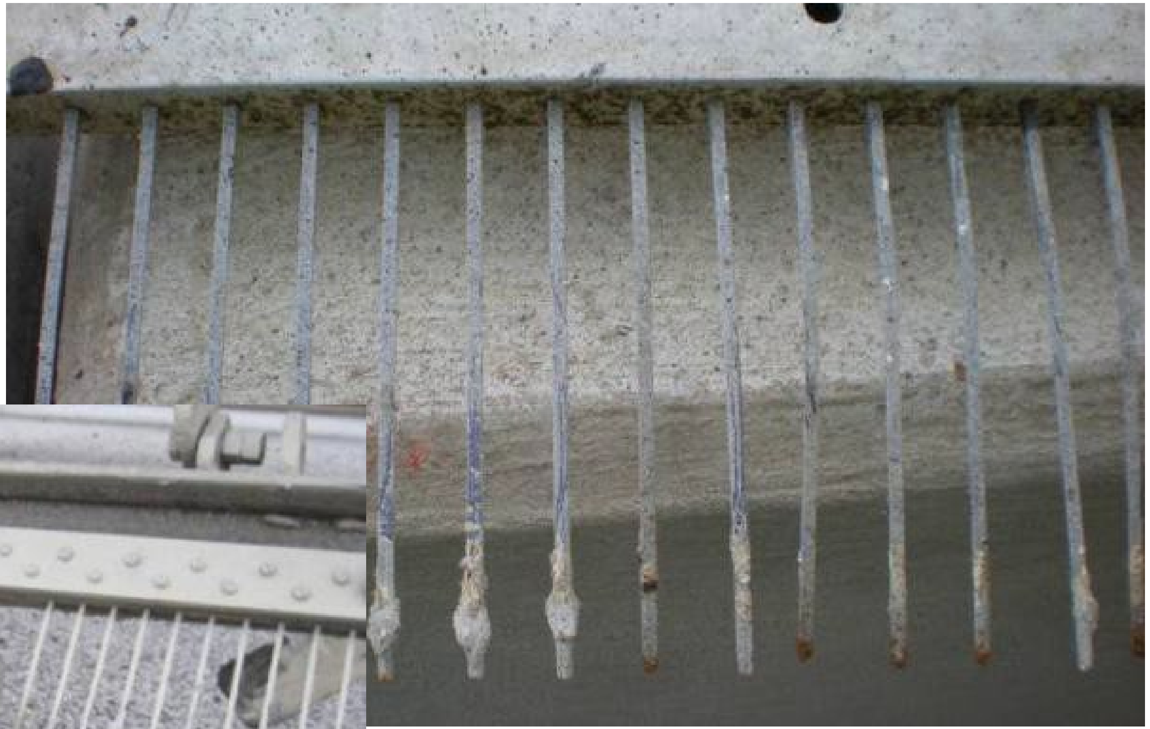
Real Time Profilers

- Helpful to assess changes in process
- Likely will not match hardened profiles

Texturing

Texturing – Recommended Practices

- Minimize positive texture
- Results in more noise
  - Clean drags
  - Clean tines
  - Straight tines



Curing

- Cure as soon as practical
- Even and complete coverage
- Consistent operating speed
- Consider two applications

Curing Compound: POOR Practice

Curing Compound: MARGINAL Practice

Curing Compound: GOOD Practice

Quality is Consistency

- Combined aggregate gradation (run regularly)
- Proper paver setup (Details, Details, Details)
- Consistent mix delivered to the paver
- Consistent head of concrete in front of the paver
- Consistent grout box height
- Consistent paver speed
- Low Vibration (less than 6500 VPM)
- NO plane or lead in the paver pan
- Less finishing behind the paver
- Keep the moisture in the slab during the early stages

Thank You

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