Performance Engineered Mixtures

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NATIONAL PAVEMENT PRESERVATION CONFERENCE
npc23
IMPACTS AND BENEFITS FROM PAVEMENT PRESERVATION

ncpp
National Center for Pavement Preservation
MICHIGAN STATE UNIVERSITY

AASHTO TSP2 PAVEMENT PRESERVATION

ROCKY MOUNTAIN WEST PAVEMENT PRESERVATION PARTNERSHIP
SOUTHEAST PAVEMENT PRESERVATION PARTNERSHIP
MIDWESTERN PAVEMENT PRESERVATION PARTNERSHIP
NORTHEAST PAVEMENT PRESERVATION PARTNERSHIP

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Outline

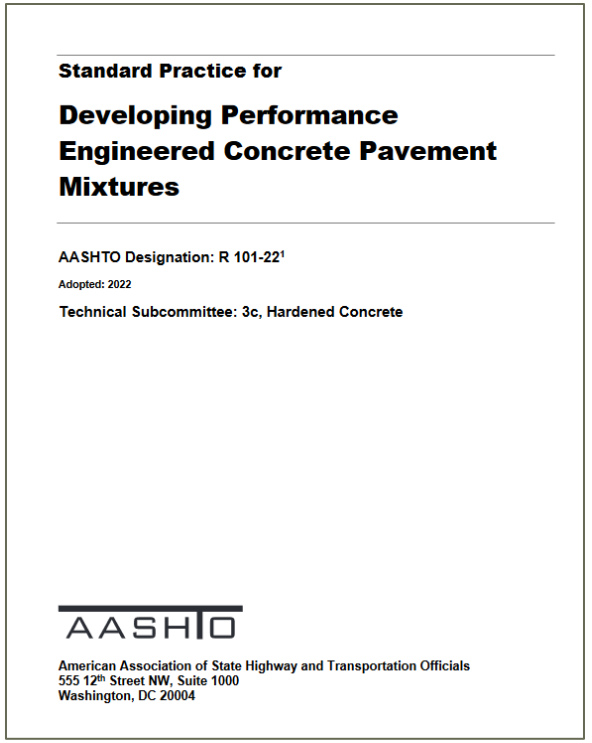
- What is PEM?
- Specifying a Better Mixture
- Testing for Critical Properties
- PEM and Preservation

Image: ACPA

What is PEM?

A Better Concrete Pavement Mixture Specification

- Understand what makes concrete “good”
- Specify the critical properties and test for them
  - Adaptable to local materials and climates
  - Test results are related to long-term performance
- Prepare the mixtures to met those specifications



Standard Practice for

Developing Performance Engineered Concrete Pavement Mixtures

AASHTO Designation: R 101-22[1]

Adopted: 2022

Technical Subcommittee: 3c, Hardened Concrete

AASHTO

American Association of State Highway and Transportation Officials
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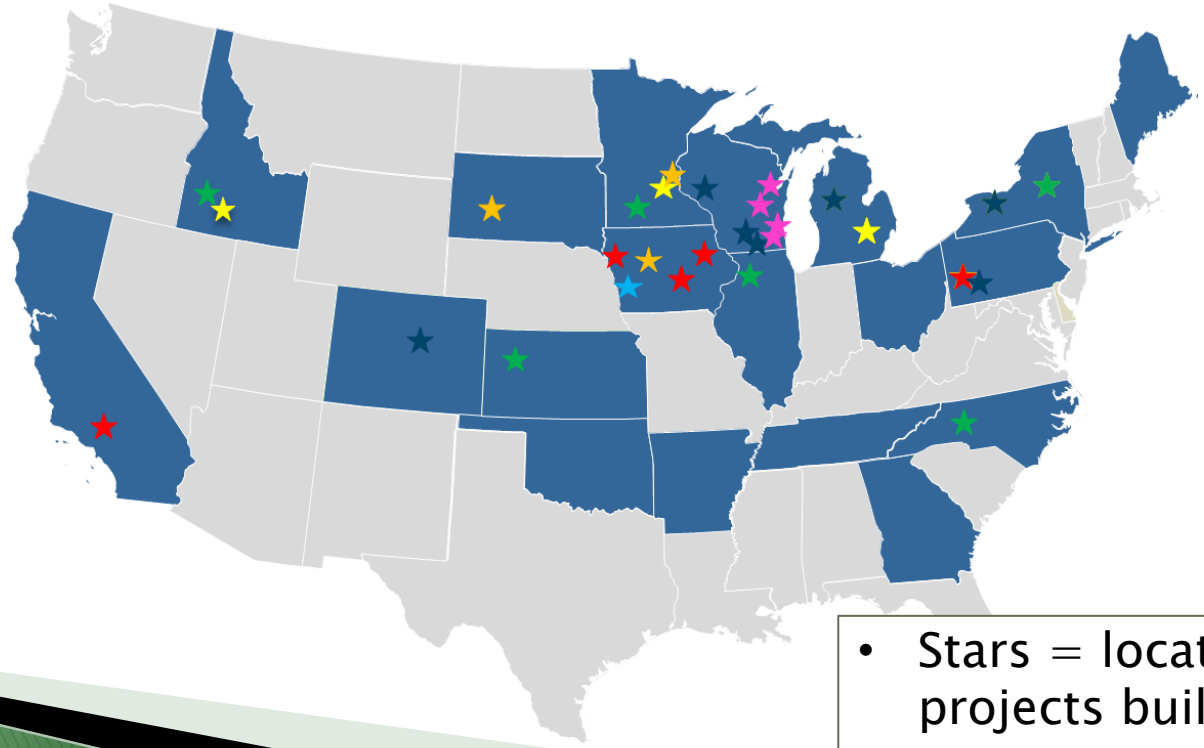
AASHTO R101

PEM Pooled Fund Study

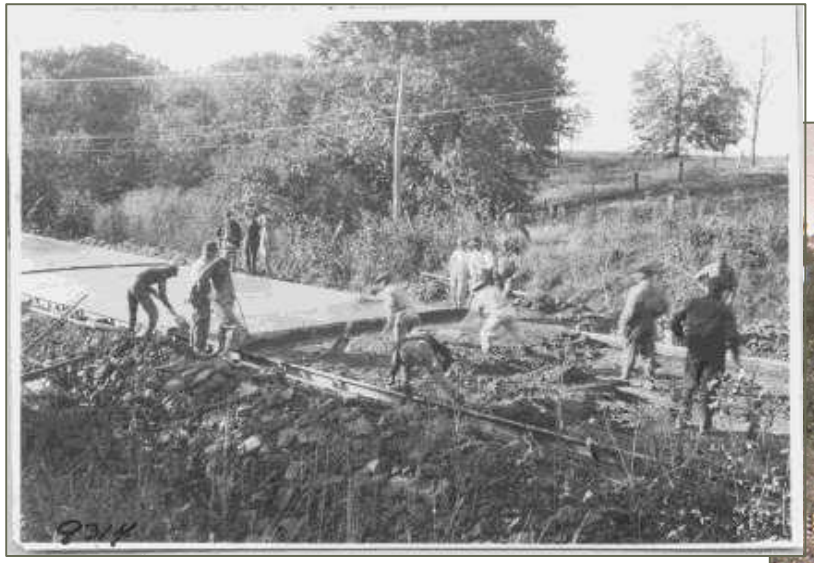
- Led and supported by 19 state DOTs, industry associations, three universities, and other researchers around the U.S.
- Final report was published earlier this year



- Stars = locations of pilot or shadow projects built between 2017 and 2022

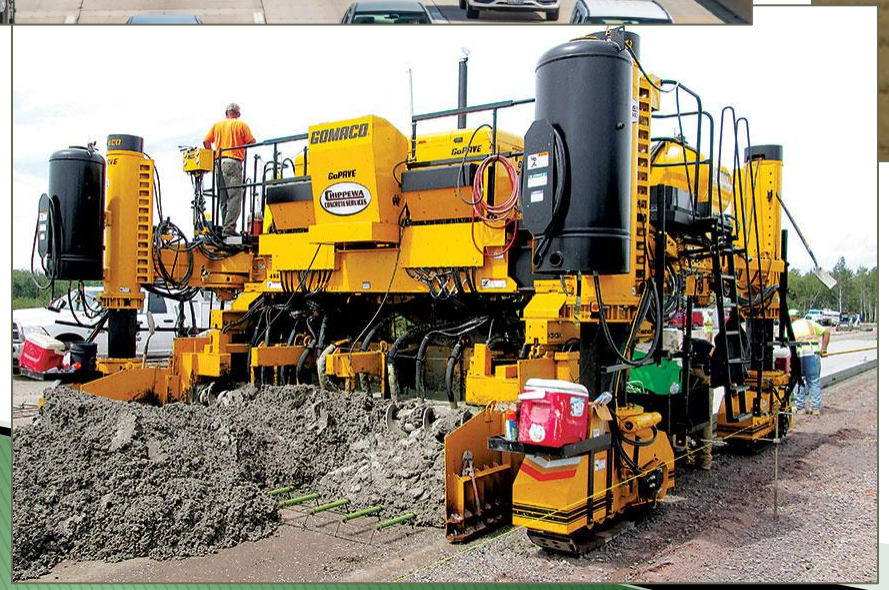
Why PEM?

- We’ve been building concrete pavements in the U.S. for more than 130 years…



Why PEM?

- …and a lot has changed!



Evolution of Concrete Materials

	1960s	2020s
Ingredients	Cement, water, rock, sand, AEA	Add SCMs, Non-Portland cements, admixtures, intermediate aggregates, limestone…
Opening Time	Weeks	Days (or hours)
Curing Time	Weeks	Days
De-icing	Sand, NaCl	Other chlorides, formates, acetates
Design life	20 years	50 years
Knowledge base	In-house	Contracted out

Evolution of Concrete Testing

Concrete

Slump Cone

1922
ASTM C143

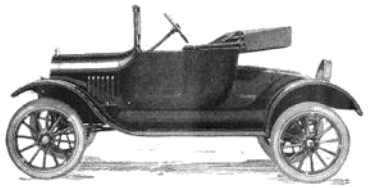
Pressure Meter

1949
ASTM C231

Rapid Chloride Permeability Test

1981
AASHTO T277

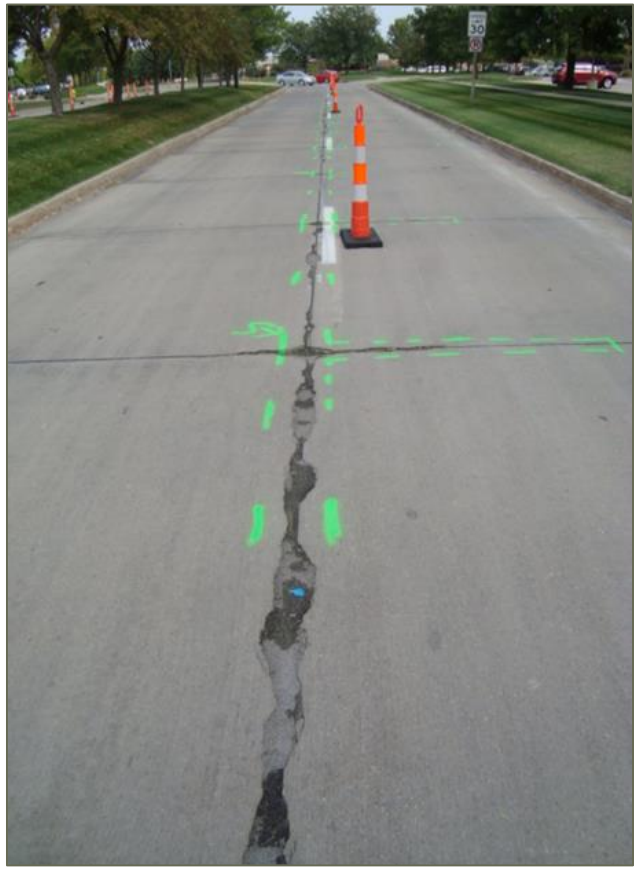
Cars



1920 1940 1960 1980 2000

Motivation

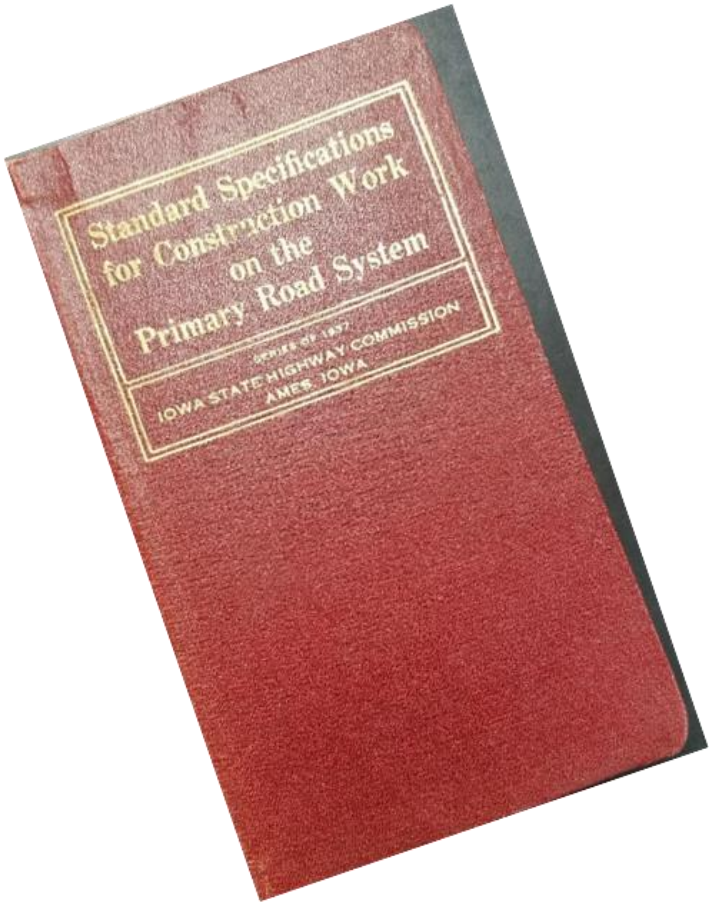
- Despite advances in concrete materials and construction, our specifications don't always deliver the longevity we expect:



Traditional Specifications

- Slump
  - Doesn't measure quality
  - No correlation with durability
- Air Content
  - Doesn't fully characterize the system
- Strength
  - No correlation with durability

We have to do better to ensure durability!



The Long-Term PEM Vision

- Concrete that delivers what is needed:
  - Longevity
  - Efficiency
    - Cost
    - Environmental impacts
  - Reliability
    - Quality
    - Identify mistakes early

Image: ACPA

Specifying a Better Mixture

The Mixture

- Require the things that matter:
  - Transport properties/permeability (everywhere)
  - Aggregate stability (everywhere)
  - Strength (everywhere)
  - Cold weather resistance (cold climates)
  - Shrinkage (dry climates)
  - Workability (everywhere)

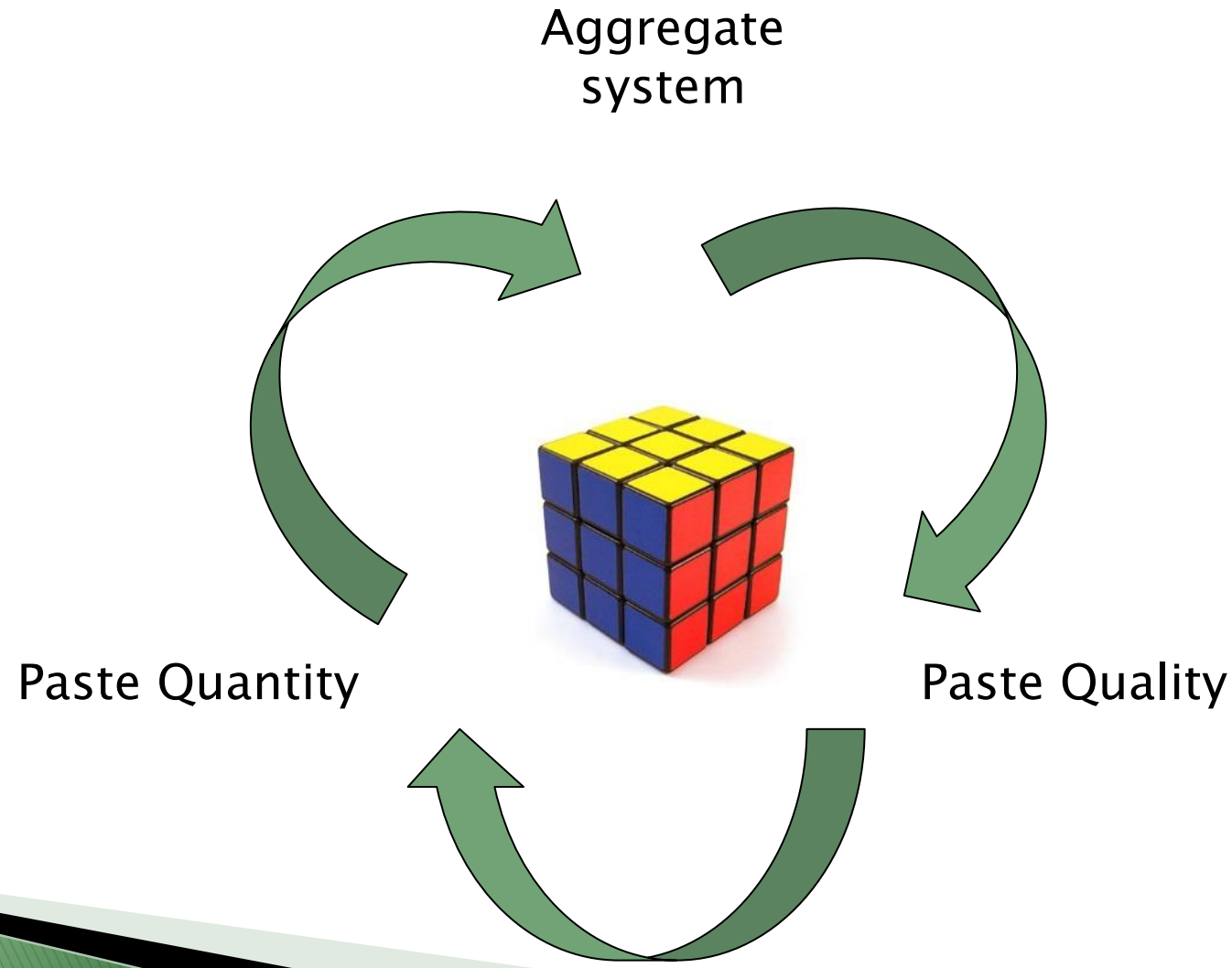
The Mixture

- Connecting design goals to concrete mixture design:
  - Paste quality
  - Aggregate system
  - Paste quantity

(Paste = cement + SCMs + water)

		Workability	Transport	Strength	Cold weather	Shrinkage	Aggregate stability
Aggregate System	Type, gradation	✓✓	-	-	-	-	✓✓
Paste quality	Air, w/cm, SCM type and dose	✓	✓✓	✓✓	✓✓	✓	✓
Paste quantity	Vp/Vv	✓	-	-	-	✓✓	-

Designing the Mixture



Paste Quality

- A high-quality paste phase is less permeable and thus less susceptible to freeze-thaw damage and other forms of deterioration
  - Low w/cm: 0.38 to 0.42
  - Use SCMs like fly ash and slag
  - Air void system
    - 5%+ in-place
    - Well-spaced
    - Stable

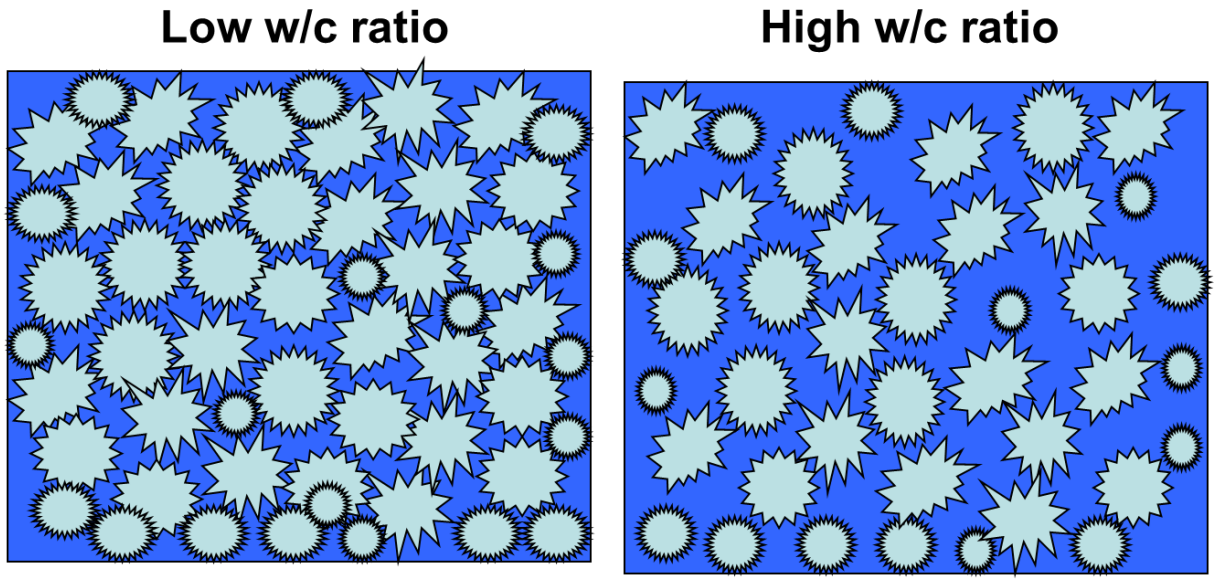


Image: Todd Hanson, Iowa DOT

Aggregate System

- We need enough paste to fill in the gaps between aggregates, plus a bit more for workability
- A well-graded aggregate system allows us to optimize the amount of paste needed

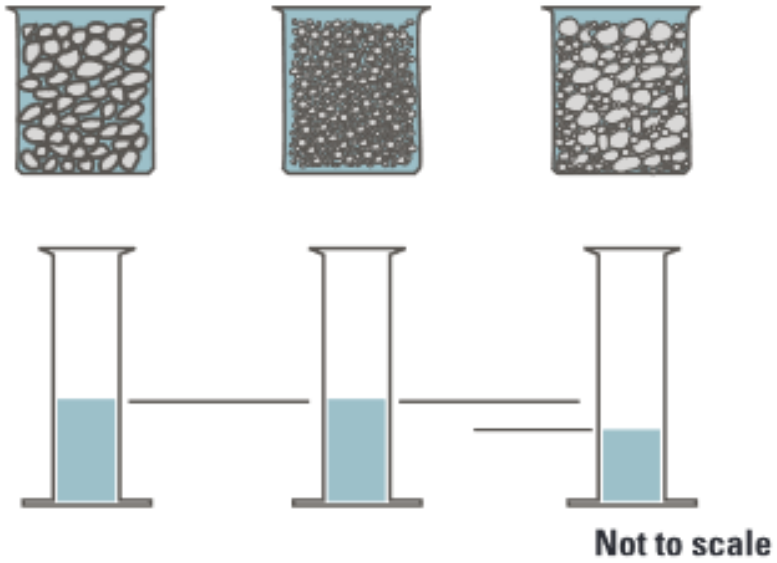
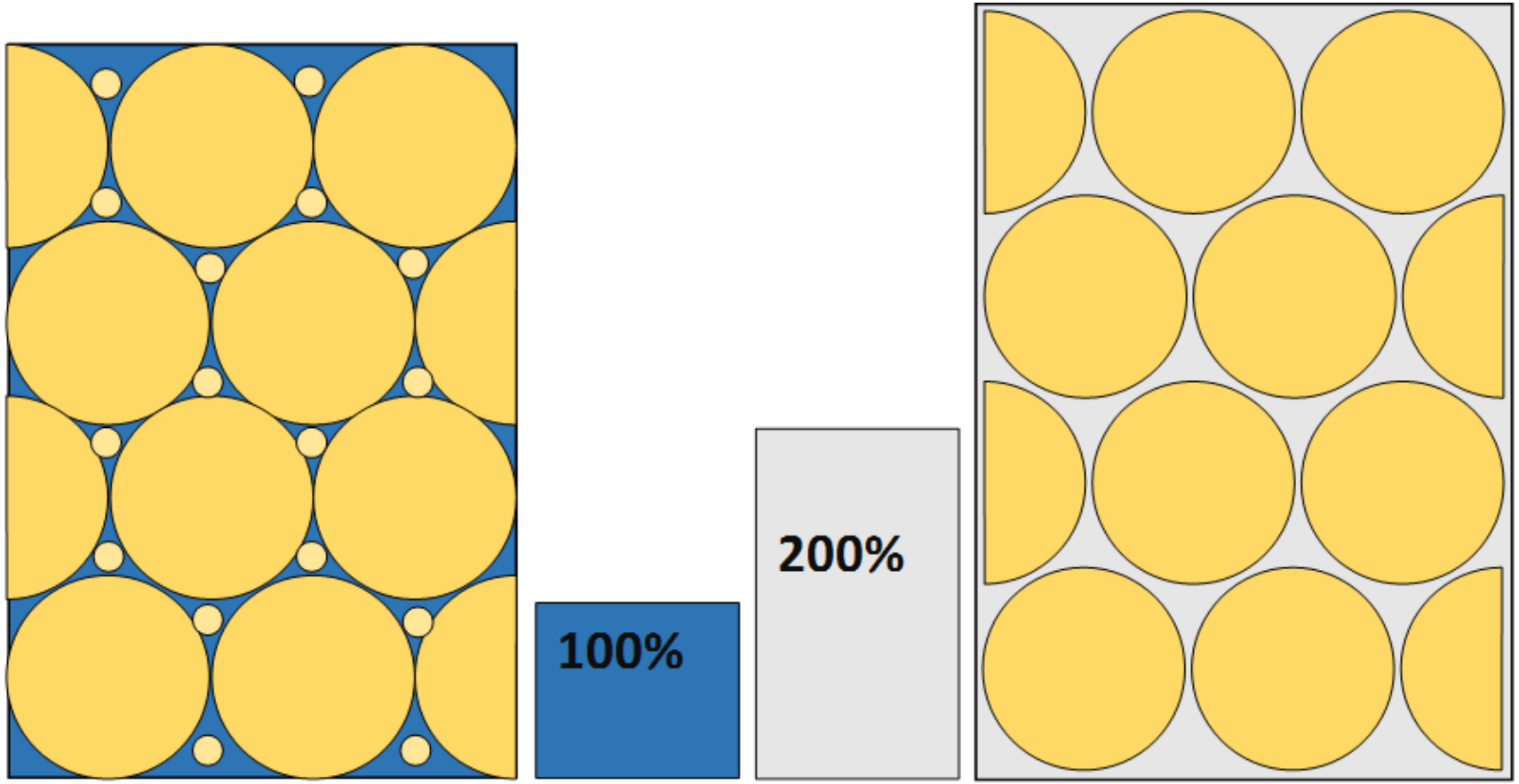


Image: PCA

Paste Quantity

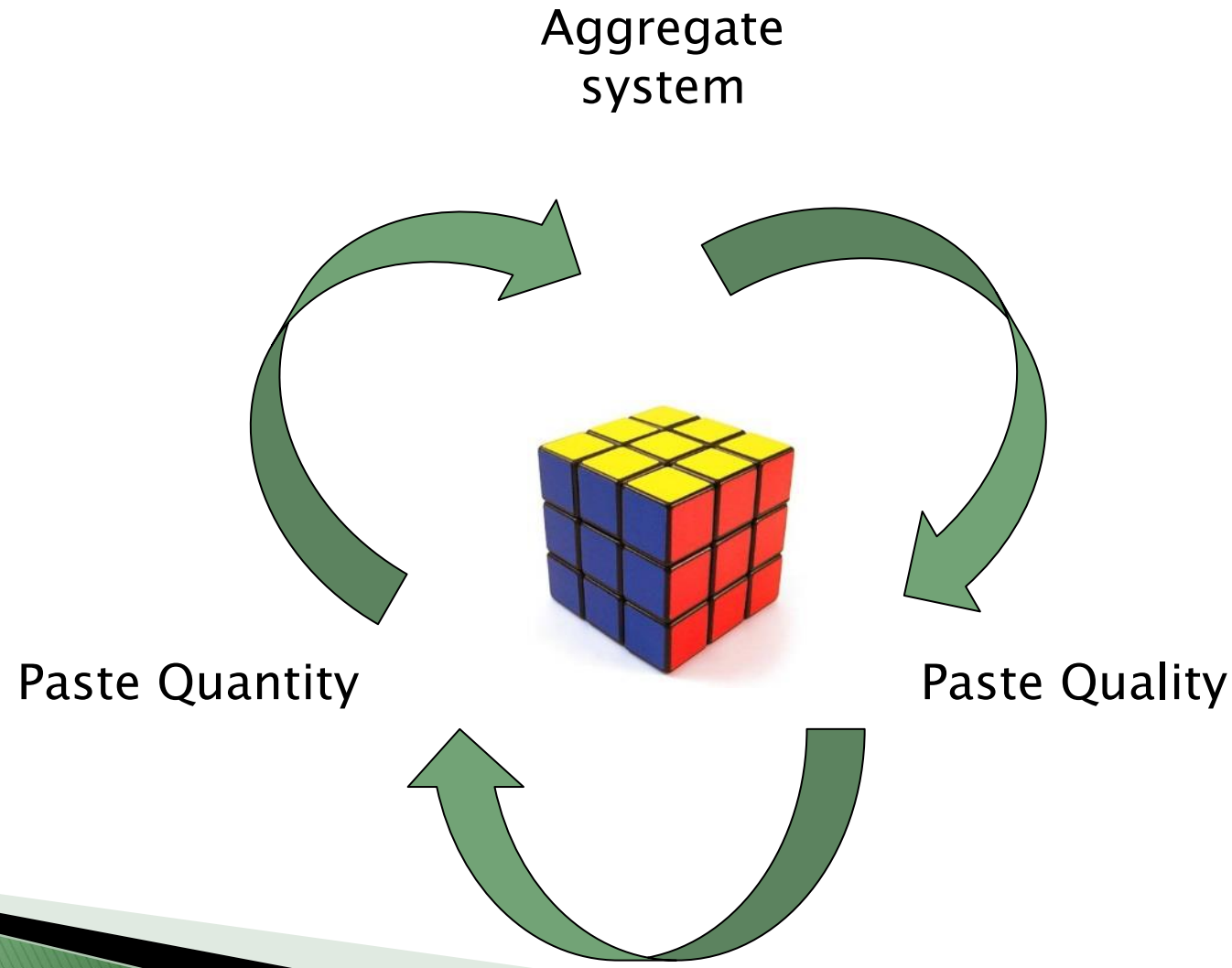
- Optimizing paste content:
  - Depends on aggregate type, gradation, and binder constituents
  - We need enough paste to achieve workability
  - Too much paste can have negative effects on permeability, shrinkage, and cost
- Avoid the misconception that we need more cement or paste for strength!
  - Designing pavement mixtures for durability will give us the required long-term strength

Designing the Mixture



Adding intermediate aggregates → less paste is required

Designing the Mixture



PEM and Sustainability

- PEM principles align nicely with reduction of concrete's embodied carbon footprint
  - Well-graded aggregate system
  - Optimized paste content
  - SCM replacement of cement
  - All changes that can be made today!

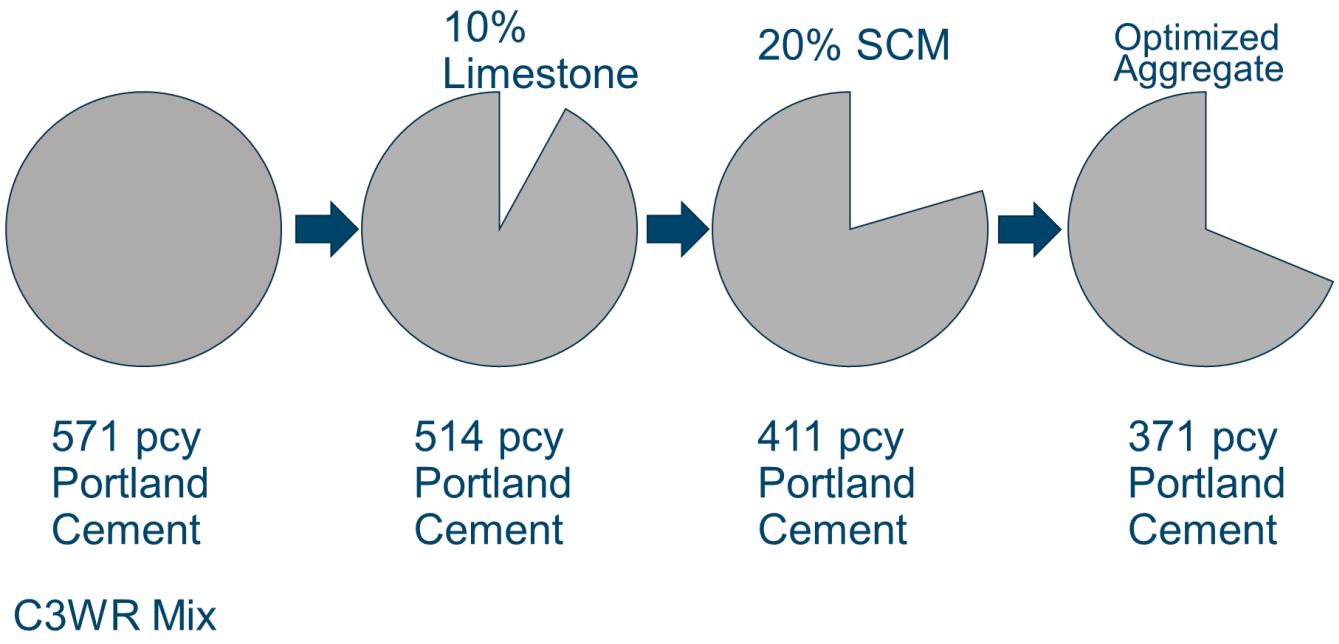


Image: Todd Hanson, Iowa DOT

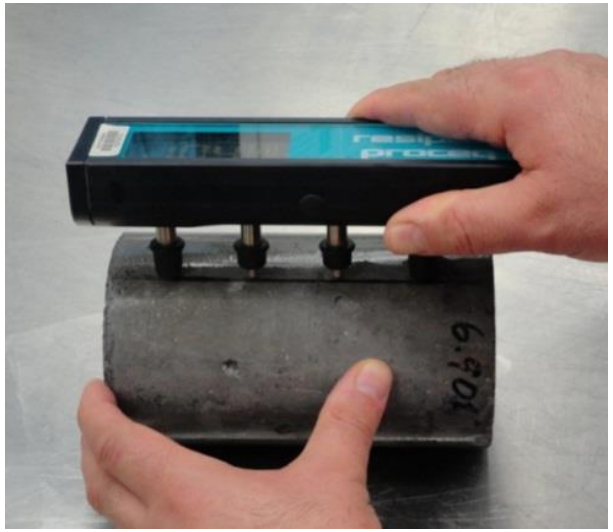
PEM and Sustainability

- PEM also provides a methodology for evaluating the next generation of materials and methods for reducing carbon
  - Harvested fly ash
  - Calcined clay
  - Natural pozzolans
  - Geopolymers
  - Ground glass
  - Carbon uptake

Testing for Critical Properties

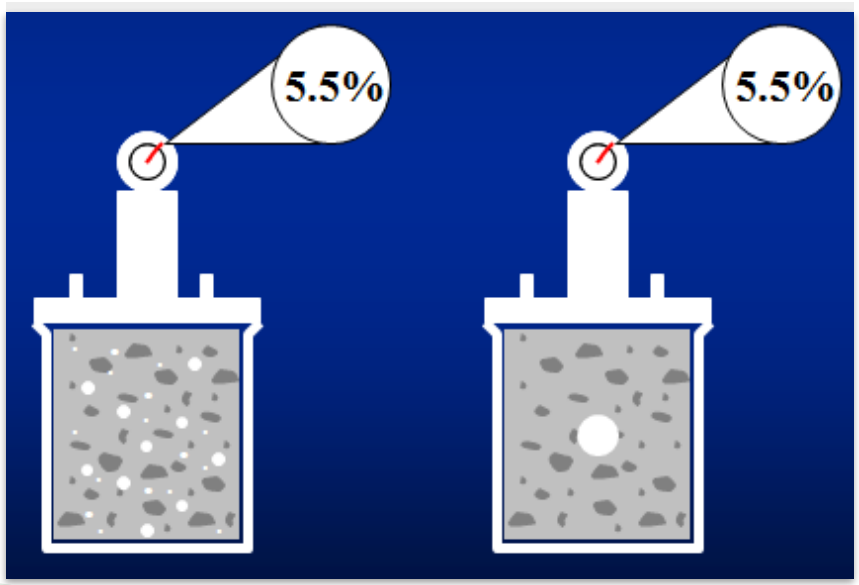
Next Generation of Test Methods

- Specify test methods that measure the properties critical to long-term performance and durability



Air Void System

- Air meters only measure the total air content even though the air void spacing is also crucial to resist freeze-thaw damage
- The Super Air Meter can characterize air void spacing in fresh concrete

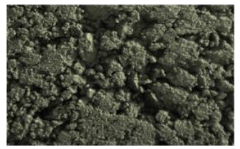
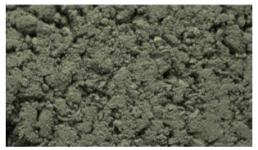


Workability

- The slump test doesn't tell us much about how the mixture responds to vibration
  - These two mixes had the same slump:

Workability

- Box Test: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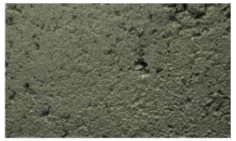
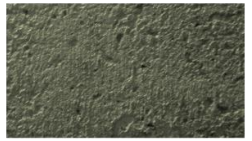
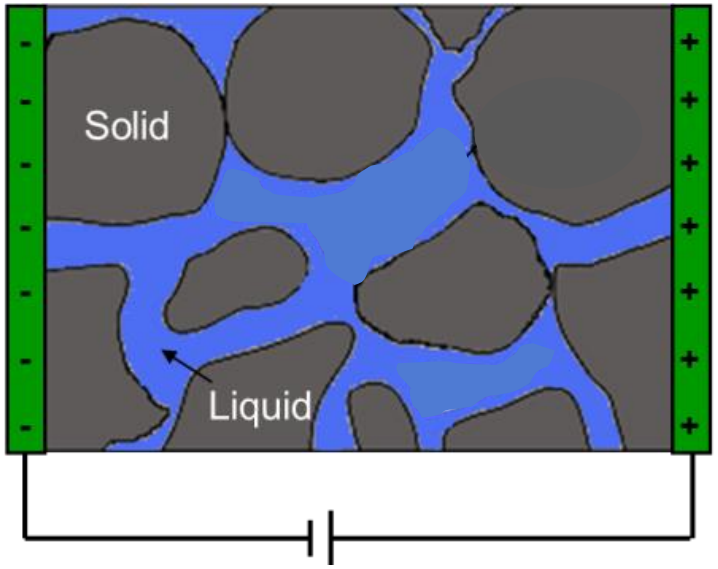
Over 50% overall surface voids.	30-50% overall surface voids.
	
2	1
10-30% overall surface voids.	Less than 10% overall surface voids.

- VKelly Test:

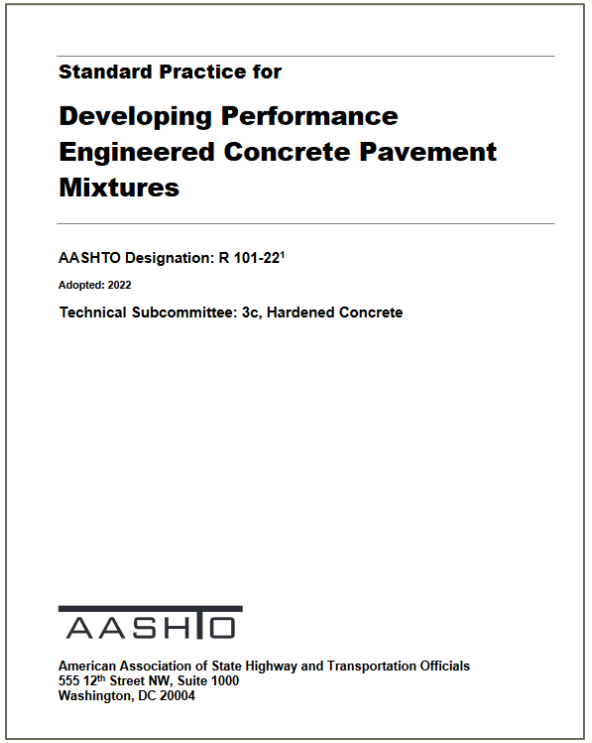
Transport Properties – Permeability

- How easily can water move through the concrete?
  - Water is part of nearly all types of durability-related problems
- Water is much more conductive than solid concrete, so we can use electrical resistivity to characterize permeability



Performance Specifications

- As new and better test methods are adopted, they can be applied to both agency acceptance and contractor QC programs
- Allows for evolution of specification to remove prescriptive constraints
  - Leverage QC
  - Maximum ability for innovation
  - More efficient use of agency resources



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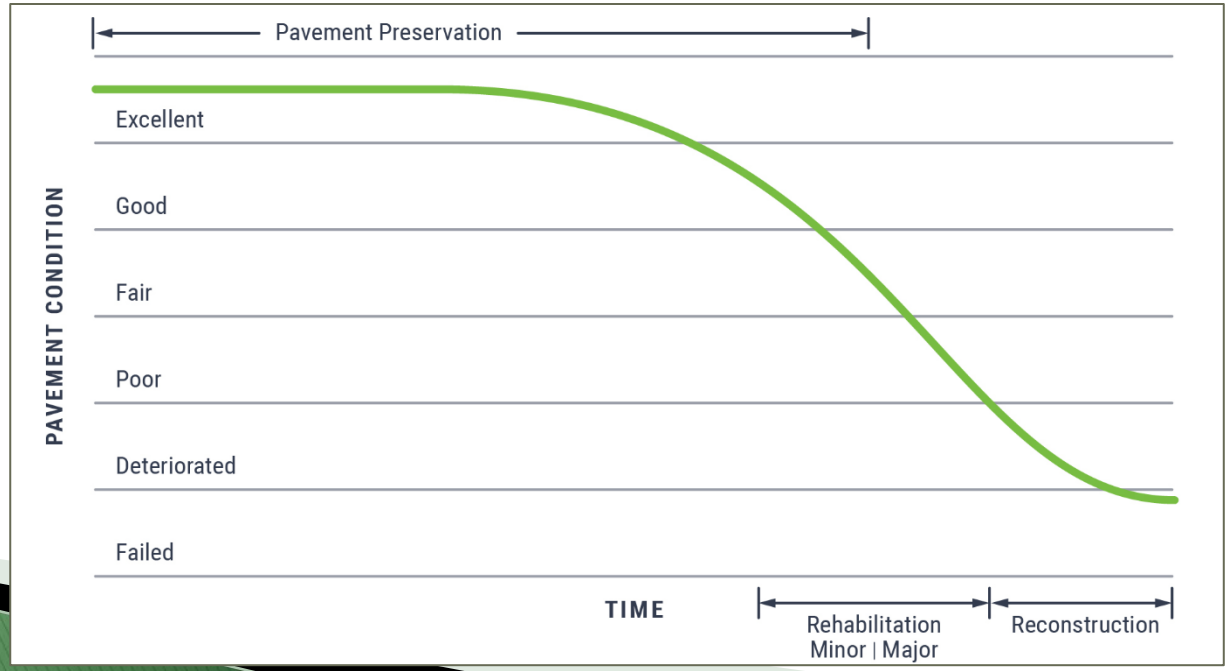
AASHTO R101

PEM and Preservation

PEM and Preservation

- The PEM program and the concept of pavement preservation share many of the same goals:
  - Extend pavement service life to major rehabilitation or reconstruction
  - Maintain pavements in good functional condition
  - Build and manage pavements in a more sustainable fashion



PEM and Preservation

- Some durability-related failures can only be fixed through more significant rehabilitation or reconstruction

PEM and Preservation

- Durability problems can also interfere with or reduce the effectiveness of preservation treatments
  - US 20, Hamilton County, Iowa:

PEM and Preservation

- Durable concrete pavements can help make pavement preservation easier and more successful
  - Easier to focus on functional issues (e.g. roughness, faulting, cracking)
  - Potentially a larger window to perform preservation treatments
  - When the concrete materials are in good condition, easier to maximize the life and effectiveness of preservation treatments

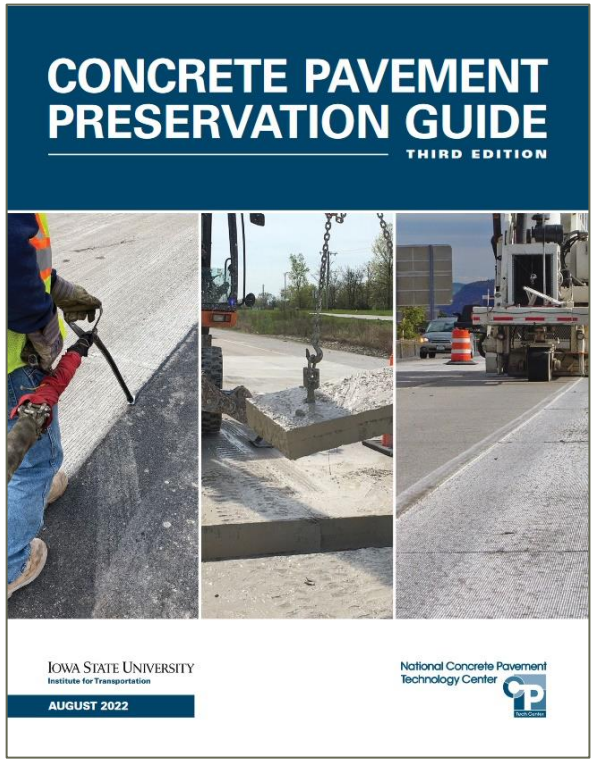
PEM and Preservation

- I-80, Adair County, Iowa
  - 10” PCC pavement constructed in 1979
  - Diamond Ground in 2020
    - Little cracking, faulting, or joint spalling
  - 2022 Condition
    - PCI = 88/100
    - IRI = 96 in./mi

PEM and Preservation

- Together, PEM and pavement preservation can combine to greatly reduce emissions associated with concrete pavements
  - Embodied carbon emissions reduced through lower CO2 impacts of mixtures and materials
  - Use phase emissions reduced by maintaining pavement in good condition and extending service life

Thank You!



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