

Enhancing Performance with Internally Cured Concrete (EPIC²)

Tim Barrett, Ph.D.
Federal Highway Administration



U.S. Department of Transportation
Federal Highway Administration

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Internal Curing (IC)

“Process by which the hydration of cement continues because of the availability of internal water that is not part of the mixing water.” – ACI Concrete Terminology



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Key Takeaways From Today

- The technology is not difficult to try
- There are no design modifications required
- Internal curing can be the belt to your suspenders when it comes to cracking and enhancing performance in bridge decks
- At the end of the day, we're just putting wet rocks in concrete

Let's make this EPIC²!



Motivation



Source: FHWA



Cracking

More than half of agencies polled report frequent occurrence of cracking in cast-in-place concrete decks during the previous 5 years.

(NCHRP Synthesis 500 Control of Concrete Cracking in Bridges, 2017)

Cracking is a key limiting factor in achieving acceptable long-term performance.



The Causes Are Many

- Concrete Mixture Design
- Structural Design
- Environmental Exposure
 - Temperature
 - Relative Humidity
- Cements
- Chemical Admixtures
- Construction Practices
- Bad Luck... the list goes on...



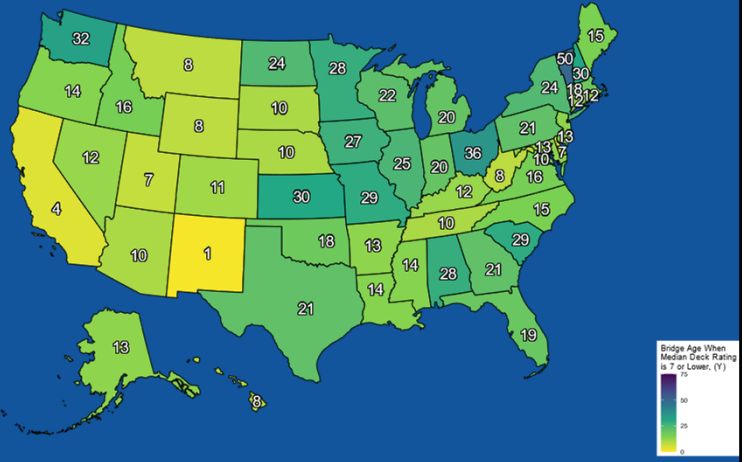
Source: FHWA

"Everything but the kitchen sink."



The Effect is Clear.

Age (years) when more than half of bridges likely have inherent cracking in deck throughout:



Data Source: NBI, 2022. Deck condition (Item 58) rating of 7 (Good) or lower.



AASHTO T-4 Construction & T-10 Concrete Design Committees Supported
NCHRP Domestic Scan 22-01: Recent Leading Innovations in the Design, Construction, and Materials Used for Concrete Bridge Decks.

“Deterioration of concrete bridge decks due to corrosion of steel reinforcement has limited the service life and increased the maintenance cost of bridge structures. Concrete bridge decks deteriorate faster than any other bridge component because of direct exposure to environment, deicing chemicals, and ever-increasing traffic loads. The magnitude of cracking and delamination of concrete bridge decks due to corrosion is a major problem when measured in terms of rehabilitation costs and traffic disruption. Steel reinforcement are often protected from elements causing corrosion or replaced with alternative non-corrodible materials in new structures.”

We all agree.



EPIC² Mission

Equip bridge, materials, and construction engineers with the knowledge and tools to design, specify, and implement internal curing into practice.



Internal Curing (IC)

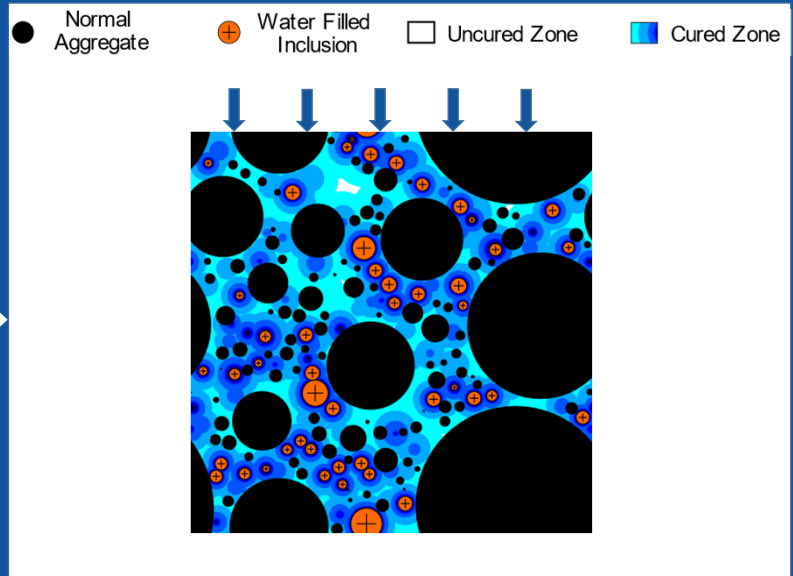
~~“Process by which the hydration of cement continues because of the availability of internal water that is not part of the mixing water.”~~

Hide the curing water inside the concrete when you make it.



Solution:

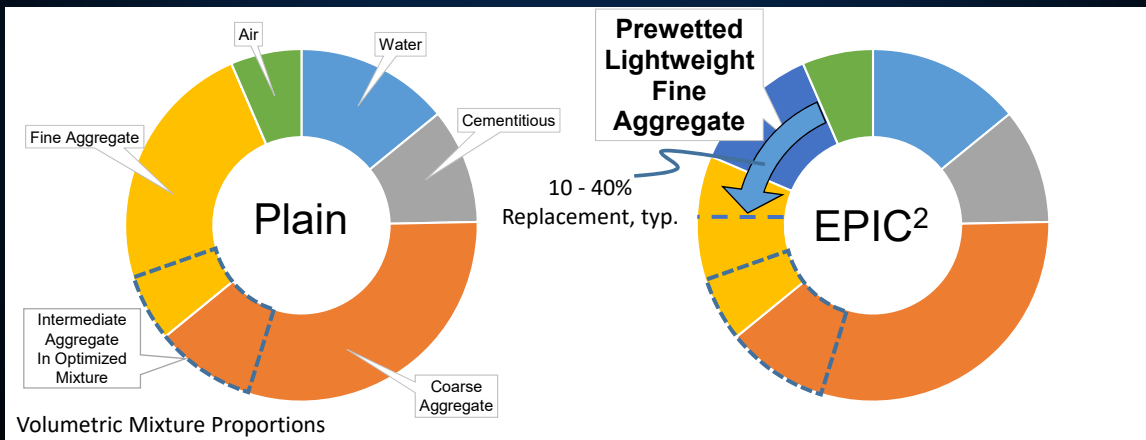
Refill the emptying pores that cause shrinkage from an internal source.



20+ years of R&D, 400+ research products. The science is clear, internal curing works.



**Current Practice:
Just Replace Some Sand.**



Mixture Proportions

Bentz & Snyder (1999)

$$M_{LWA,OD} = \frac{C_f \cdot CS \cdot \alpha_{max}}{S \cdot \phi_{LWA}}$$

- C_f : Cement Content (lb/yd³)
- CS : Chemical Shrinkage (lb water / lb cementitious)
- α_{max} : Degree of Hydration (%)

Typically:

Supply 7 lb of water per 100 lb of cementitious (CS = 0.07)

- $M_{LWA,OD}$: Mass of LWA (oven dry basis)
- ϕ_{LWA} : LWA Absorption (%)
- S : Saturation Factor (%)



Spreadsheet Design

Developed as a part of the report for INDOT implementation.

Available for download:

<https://docs.lib.purdue.edu/jtrp/1574/>
[APPENDIX H. Mixture Design Worksheet.xlsx](#)

Webinar training module available now!



“Mixture Design” Tab:

- Plain mixture design (input)
- Internal curing properties (input)
- IC mixture design (output)



Center for Accelerating Innovation

Enhancing Performance with Internally Cured Concrete (EPIC²)

Internal curing increases concrete's resistance to early cracking, allowing the production of higher-performance concrete that may last more than 75 years.

Shrinkage cracking in concrete is a key limiting factor in achieving acceptable long-term performance in concrete bridges, roads, and repairs. When this cracking occurs at an early age, it leaves the concrete and embedded reinforcement exposed to degradation, reducing the service life of the structure. Unlike conventional curing where water is supplied on the concrete's surface, internal curing provides a source of moisture from inside the concrete mixture, improving its resistance to cracking and overall durability.

Improved Infrastructure That Lasts Longer

Internal curing targets and mitigates the source of shrinkage cracking by providing curing water integrally to the concrete mixture. Over the last 30 years, extensive studies have shown that internal curing addresses the root cause of self-drying shrinkage that is particularly problematic in lower water to cementitious materials ratio concrete.

This material level technology can be employed in any concrete mixture with an adjustment to mixture proportions. The most widely used approach includes pre-entire lightweight aggregates, which have a high absorption capacity and are naturally compatible with common concrete production practices. A portion of the normal weight fine aggregate in the concrete mixture is replaced with a pre-wetted lightweight fine aggregate. The saturated, porous fine aggregate in the concrete mixture distributes the curing water throughout the concrete body. As the concrete loses water naturally due to continued hydration or environmental exposure, water is pulled out of the lightweight aggregate and creates internal curing. This allows cementitious microstructure pores to be refilled before they become empty, avoiding the negative pore pressures that cause concrete to shrink.

Applications

Internal curing is primarily used in concrete bridge decks where a reduction in shrinkage coupled with better permeability mixture design can provide substantially improved protection to the steel reinforcement. In paving and overlays, the technology reduces the magnitude of crack widths and curing deformations and can be used to extend the spacing between engineered joints. For patching and repair materials, internal curing minimizes the potential for restrained shrinkage cracking associated with high cement content mixtures designed to develop strength rapidly.

Benefits

Viability: Internal curing can be used anywhere traditional concrete is used. It follows the norms of industrial concrete production, making it accessible to any producer already familiar with the state of practice.

Durability: Internal curing mitigates shrinkage cracking that is particularly problematic in low water to cementitious materials ratio concrete, allowing construction with lower permeability concrete to improve durability.

Cost savings: Higher durability concrete mixtures can last several decades longer.

Contacts

Tim Barnett
FHWA Turner-Fairbank Highway Research Center
(202) 485-3422
Timothy.Barnett@dot.gov

Mike Prall
FHWA Office of Infrastructure
(202) 512-4817
Michael.Prall@dot.gov

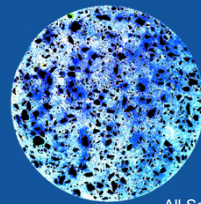
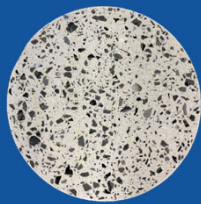
Robert Conway
FHWA Resource Center
(202) 366-6508
Robert.J.Conway@dot.gov

Ragga Holt
FHWA Office of Bridges and Structures
(202) 366-6508
Ragga.Holt@dot.gov

Resources

Fast sheet
Subscribe to Enhancing Performance with Internally Cured Concrete (EPIC²)
FHWA Concrete Clips
Internal Curing Video
Expanded Shrink, Clay, and Sand Institute (ECSi)
Internal Curing Videos
NIST Internal Curing of Concrete Information Sources
New York State DOT Standard Specifications
Report on Indiana DOT's Construction of Bridge Decks with Internal Curing

Where Should IC Be Used?



All Source: FHWA



1. Bridge Decks

Structures that need enhanced service life.



Source: FHWA



2. Repairs

- High Early Strength
- High-paste Content

Elements or mixtures that have high shrinkage or cracking potential.



Source: FHWA



3. Pavements

- Low Curl Performance
- Extended Control Joint Spacing

Any element where reduced shrinkage adds desired performance.



Source: FHWA



Advantages of Internal Curing

- Works automatically
- Compatible with current concrete practice
- Simple modification to concrete mixture design proportions
- No modifications to structural design process
- Economical
- Unlike some things in construction, it's hard to forget to do
- Works automatically

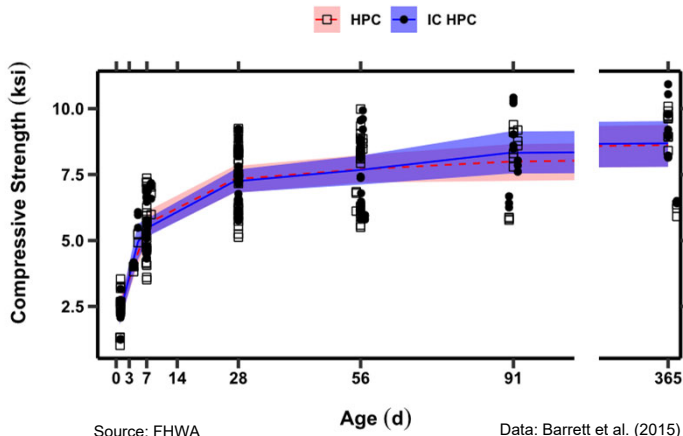


Performance Benefits

- Substantial reduction in total cracking potential
- Improved resistance to:
 - plastic shrinkage
 - drying shrinkage
 - thermal shrinkage or gradients
- Continued and extended hydration of cement
- Creates potential for very high durability concrete with mitigation of cracks typical in traditional “high performance concrete”
- Secondary benefits such as improved alkali silica reaction resistance



Compressive Strength



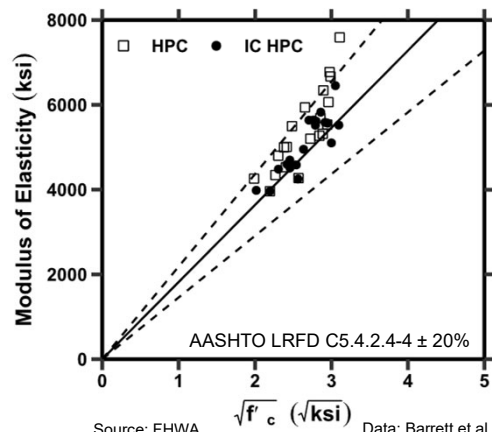
- Compressive strength may vary by small amounts in individual trials
- Variation as a class of concrete not significant
- If employing HPC, typically much stronger than designed

IC HPC: Internally cured, High performance concrete
 HPC: High performance concrete

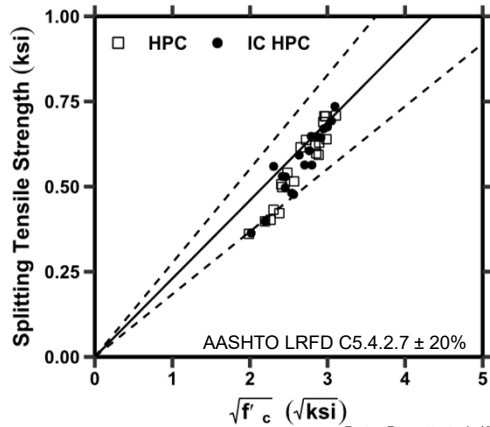


Young's Elastic Modulus

- Modulus of elasticity follows code expressions for conventional concrete
- This is not *lightweight* concrete ($\lambda=1$)
- Typical unit weight $\sim 135+$ lb/ft³



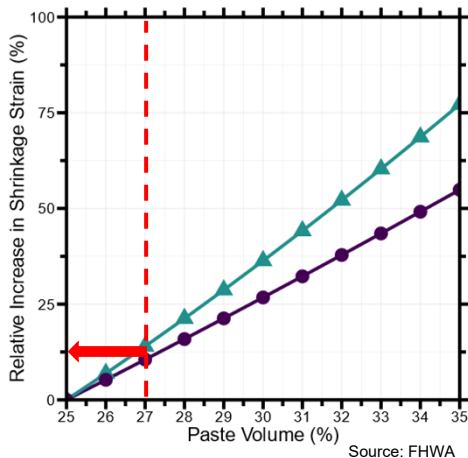
Tensile Strength



- Tensile strength follows code expressions for conventional concrete
- This is not *lightweight* concrete ($\lambda=1$)



Shrinkage Considerations



Shrinkage is a paste volume property

Pickett's Eq. for concrete shrinkage strain

$$\epsilon_c = \epsilon_p(1 - V_A)^n$$

ϵ_c : shrinkage of concrete

ϵ_p : shrinkage of paste

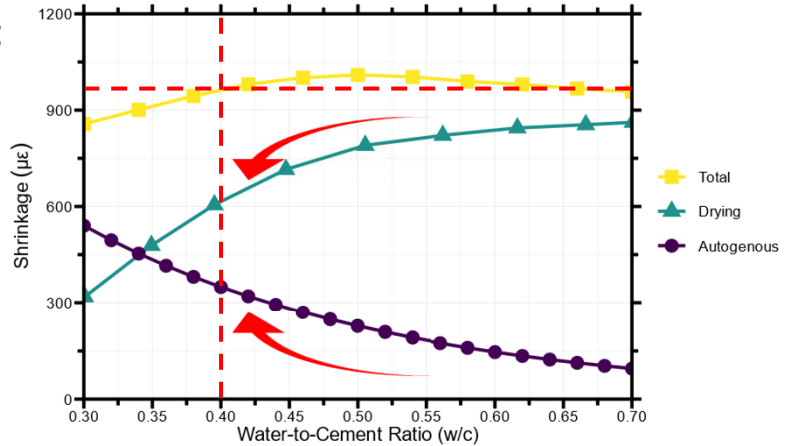
V_A : volume fraction of aggregate

n : aggregate stiffness parameter



Shrinkage Considerations

- For fixed volume of paste:
 - Drying shrinkage higher with higher w/c
 - Autogenous shrinkage higher with lower w/c
 - Total shrinkage approximately constant across w/c



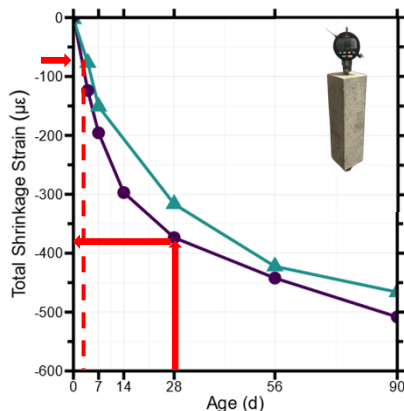
70% Volume of Aggregate:



Source: FHWA after Weiss (2022)
Data: Neville (1995) & Rasoolinejad et al. (2019)

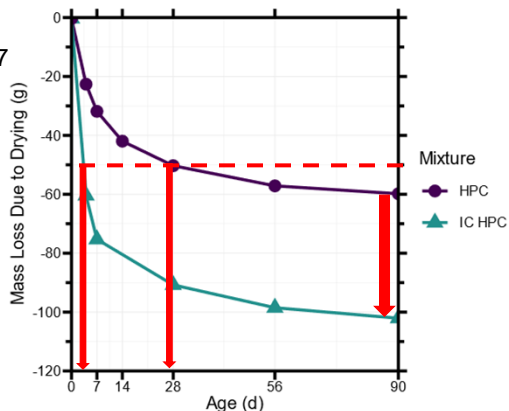


“Drying” (Total) Shrinkage



Source: FHWA
Data: Barrett et al. (2015)

Modified ASTM C157

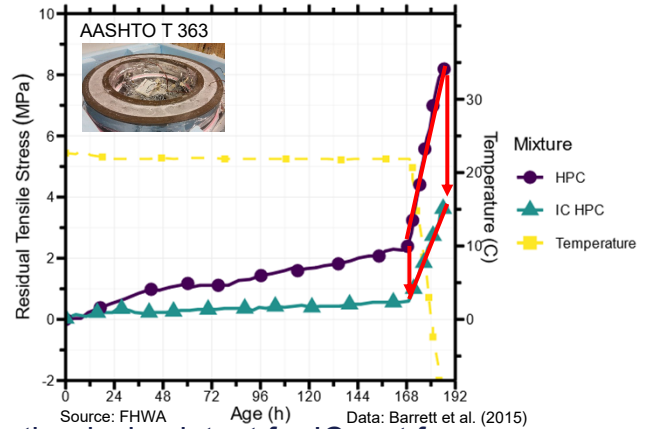
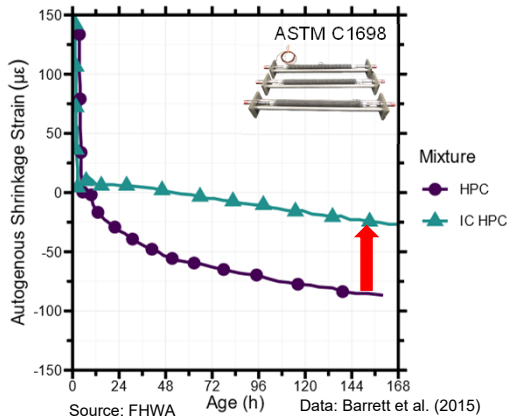


Source: FHWA
Data: Barrett et al. (2015)

Not a test that should be necessarily specified



Autogenous Shrinkage

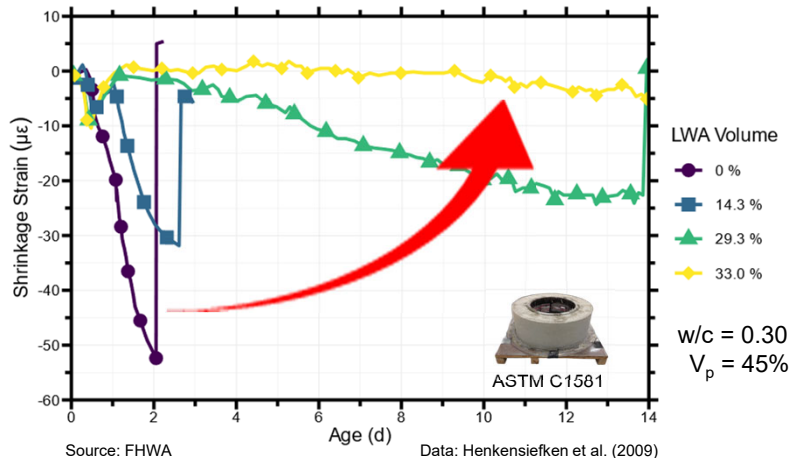


These are specialized tests that verify the design intent for IC, not for spec.



Combined Drying & Autogenous Shrinkage

- Benefits remain clear
- Providing sufficient curing water by amount of LWA is key
- Not a test that should be specified



w/c: water-to-cement ratio (mass basis)
V_p: volume of paste

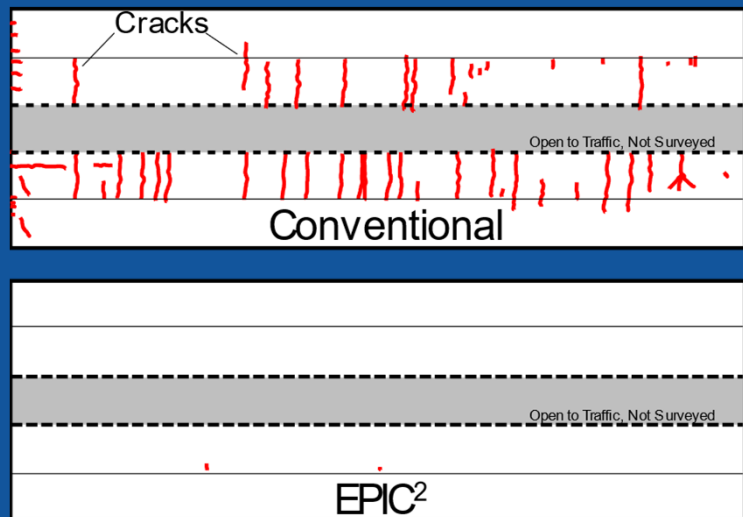
Performance Relative to Shrinkage Reducing Admixtures?

Similar reduction to cracking potential
as industry-standard optimum dosage of
1.5 gallon per cubic yard



“Head to Head”
Comparison

Cracking after
1 Year
of Service



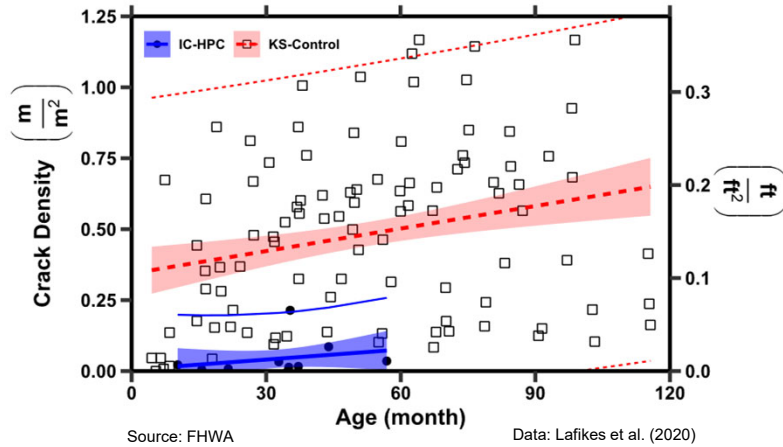
Source: FHWA

Data: Wang et al. (2019)



Shrinkage Cracking Performance

Cracking Substantially Reduced



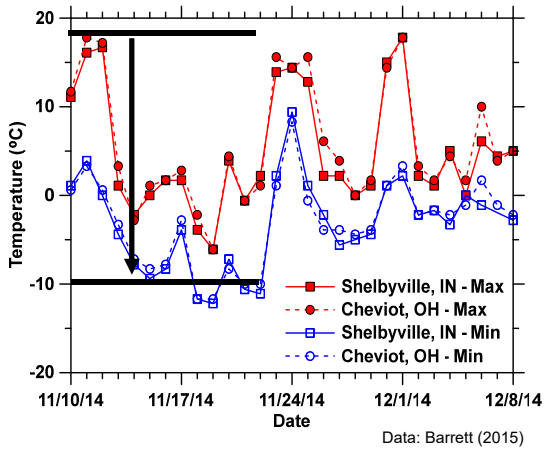
Source: FHWA

Data: Lafikes et al. (2020)



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Thermal Cracking Performance



Data: Barrett (2015)



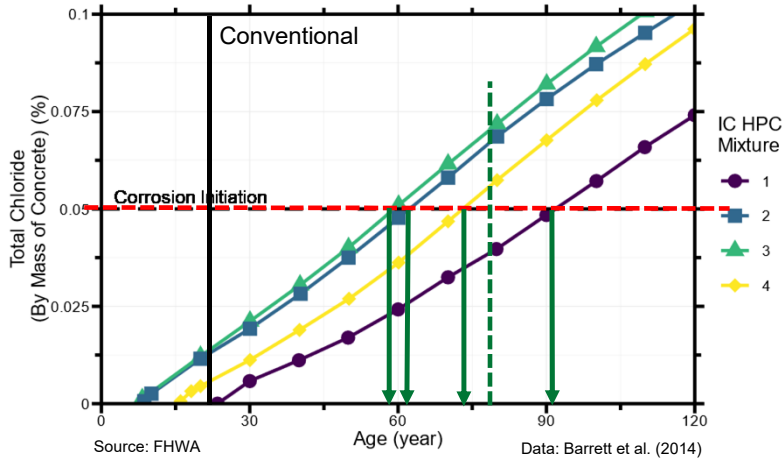
All Image Sources: FHWA

Internal curing lowers the coefficient of thermal expansion
Higher resistance to thermal cracking



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Estimated Service Life



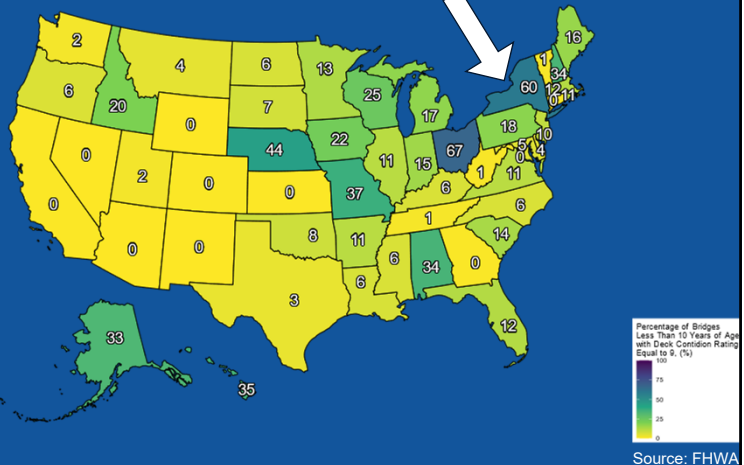
Estimated Corrosion Initiation Service Life:

60-90 years
~3 to 4.5x increase



Percentage of Bridges,
Less Than 10 Years of Age,
Deck Condition Rating of 9

New York was the first to institutionalize, nearly a decade ago.



Data Source: NBI, 2022.
Deck condition (Item 58) rating of 9 (Excellent Condition).



Life Cycle Cost Analysis

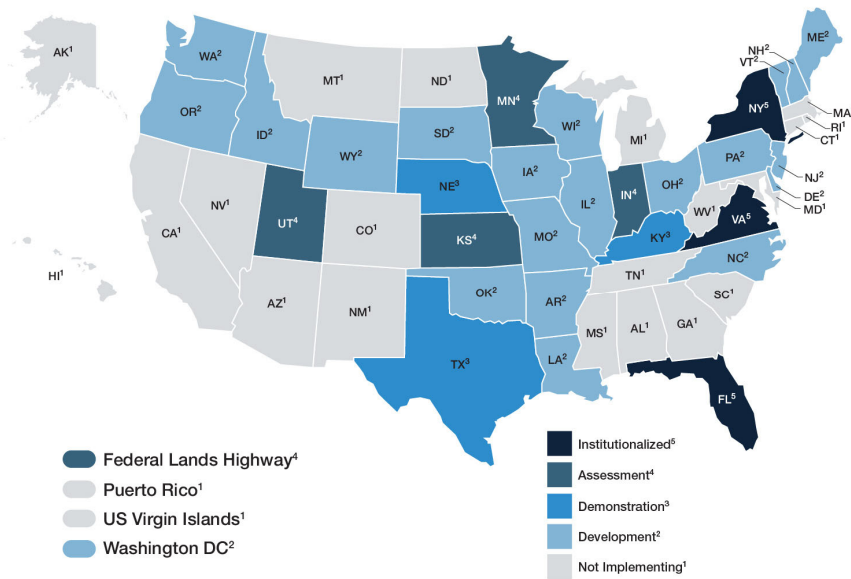
Internally cured, high performance concretes have been estimated to reduce lifecycle cost by 29 - 70% compared to control

Sources: Cusson et al. (2010), Guo et al. (2014), Wang et al. (2019)



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Baseline (April 2023)



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Path to Success

Educate

- Case Study Summary
- Targeted Workshops & Webinars
- Training Videos

Specify

- Guide Specification
- Design Examples
- QC/QA Guidance

Pilot

- Best Practices & FAQ Guide
- Peer Exchange & Demonstrations
- Centrifuge Access

Monitor

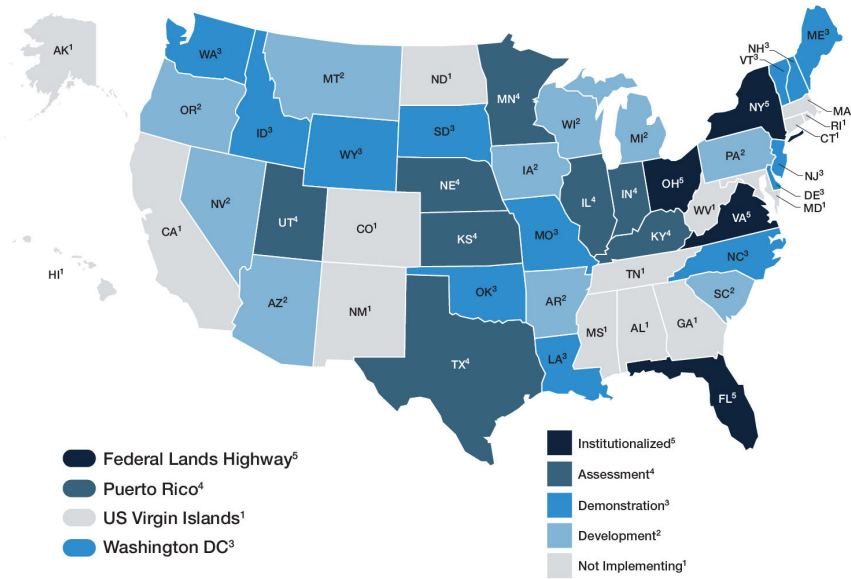
- Crack Inspections
- Post-Construction Remedial Work Occurrences
- Deck Condition Ratings

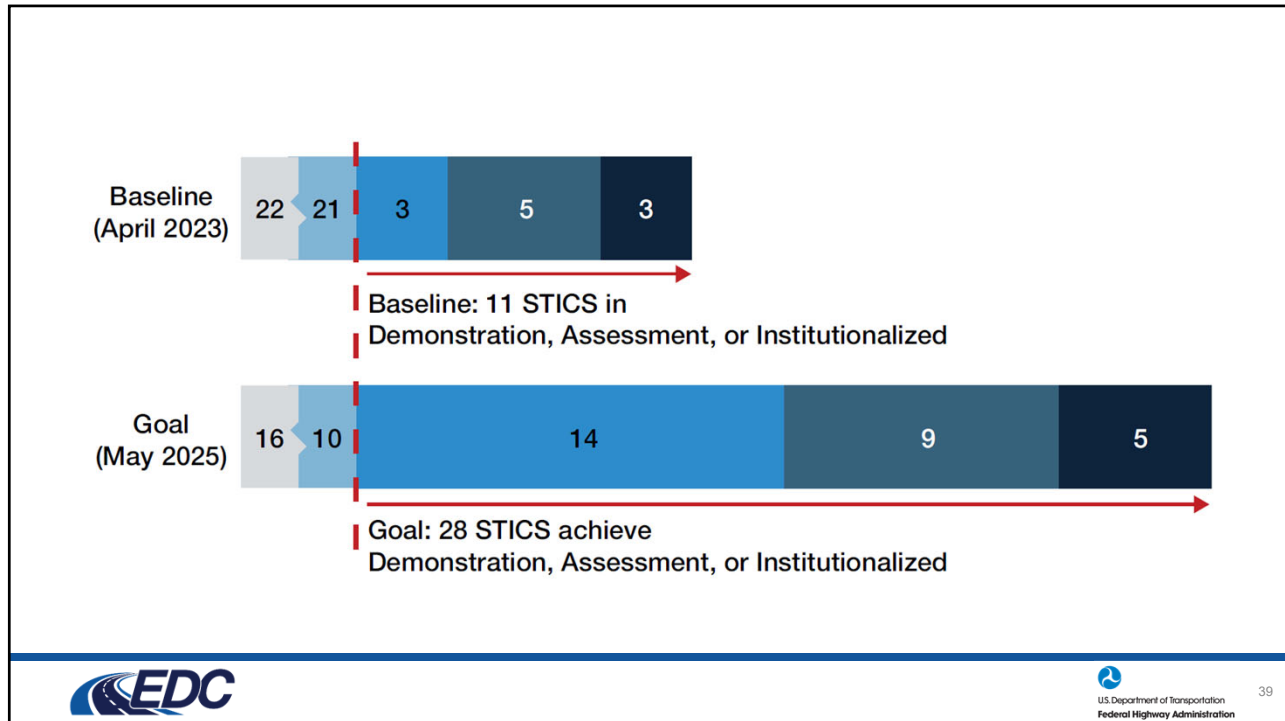
That Would Be:

EPIC²



Goal (May 2025)





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Theory & Performance of Internally Cured Concrete



Mixture Proportioning for Internally Cured Concrete



Lessons Learned in NY, IN, and LA



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Thank you

Questions / Comments Please?



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