# Enhancing Performance with Internally Cured Concrete (EPIC$^2$)

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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 EPIC$^2$!

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# Motivation

Source: FHWA

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# 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.

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# 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."*

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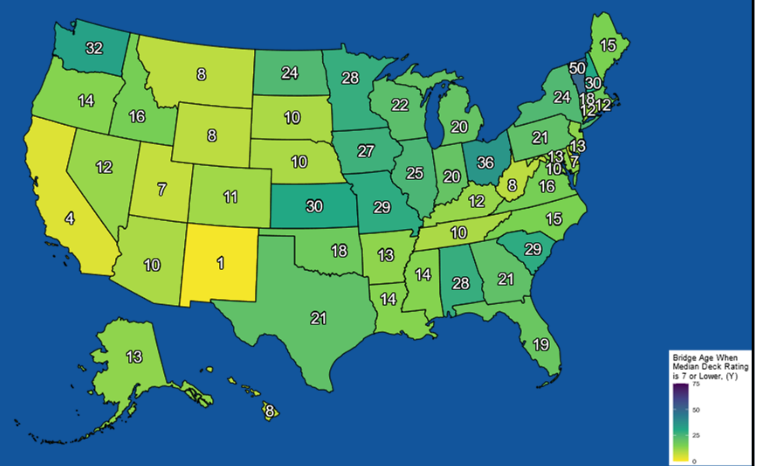
# The Effect is Clear.

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




Source: FHWA

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.

# EPIC$^2$ Mission

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

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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.”~~

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

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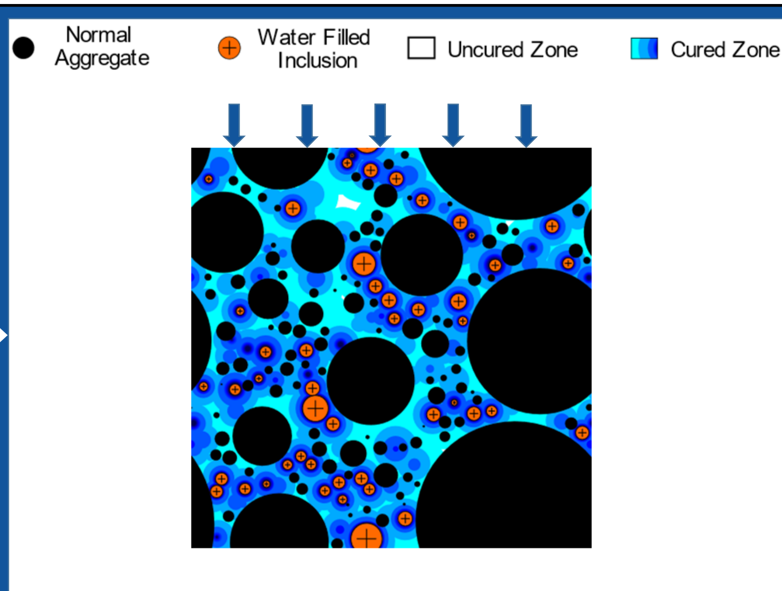
## Solution:

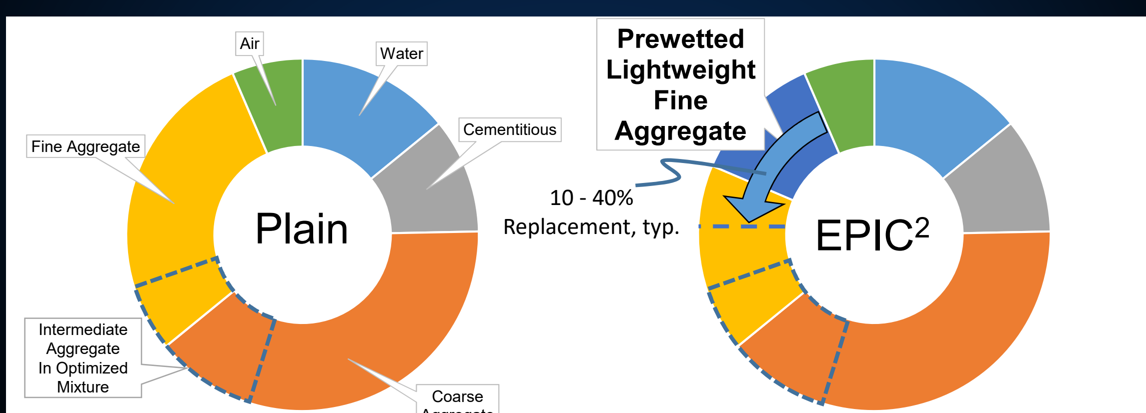
Refill the emptying pores that cause shrinkage from an internal source.




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



# Current Practice: Just Replace Some Sand.




Volumetric Mixture Proportions

# Mixture Proportions

*Bentz & Snyder (1999)*

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

Typically:

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

$C_f$: Cement Content (lb/yd$^3$)

$CS$: Chemical Shrinkage (lb water / lb cementitious)

$\alpha_{max}$: Degree of Hydration (%)

$M_{LWA,OD}$: Mass of LWA (oven dry basis)

$\phi_{LWA}$: LWA Absorption (%)

$S$: Saturation Factor (%)



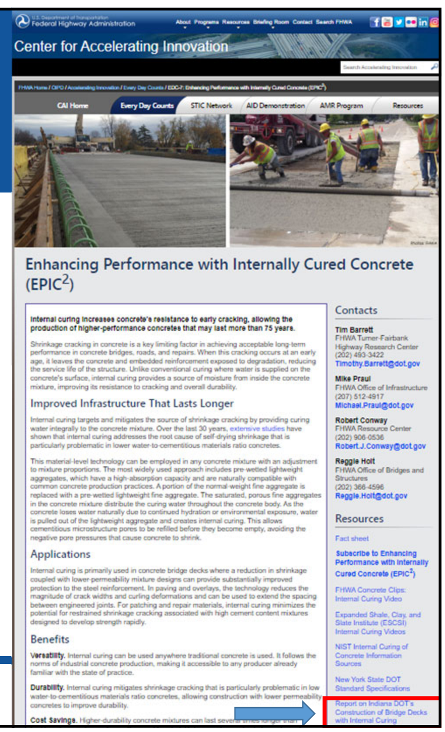
# Spreadsheet Design

Developed as a part of the report for INDOT implementation.

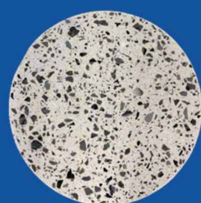
Available for download:
https://docs.lib.purdue.edu/jtrp/1574/
APPENDIX H. Mixture Design Worksheet.xlsx

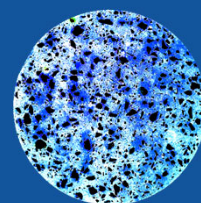
Webinar training module available now!

"Mixture Design" Tab:
- Plain mixture design (input)
- Internal curing properties (input)
- IC mixture design (output)



# Where Should IC Be Used?





All Source: FHWA

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## 1. Bridge Decks

*Structures that need enhanced service life.*

Source: FHWA

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## 2. Repairs
-High Early Strength
-High-paste Content

*Elements or mixtures that have high shrinkage or cracking potential.*

Source: FHWA

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## 3. Pavements
-Low Curl Performance
-Extended Control Joint Spacing

*Any element where reduced shrinkage adds desired performance.*

Source: FHWA

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## Advantages of Internal Curing

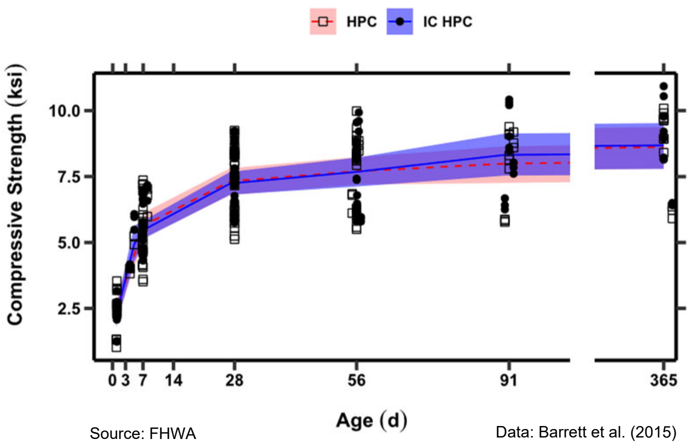
- Works automatically
- Compatible with current concrete practice
- Simple modification to concrete mixture design proportions
- No modifications to structural design process
- Economical
- Unlike some things in construction, it's hard to forget to do
- Works automatically



## 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




Source: FHWA

Data: Barrett et al. (2015)

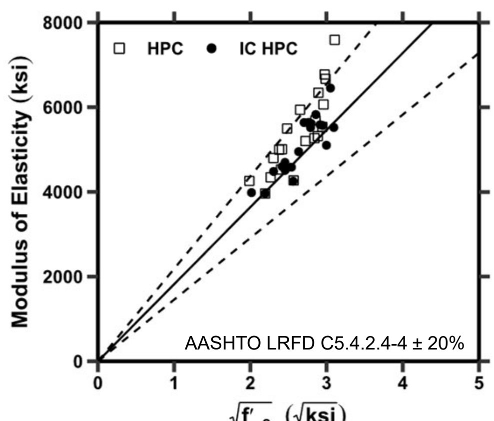
- Compressive strength may vary by small amounts in individual trials
- Variation as a class of concrete not significant
- If employing HPC, typically much stronger than designed

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



# Young's Elastic Modulus

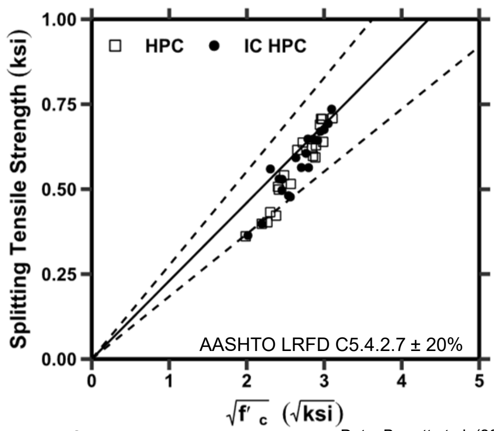
- Modulus of elasticity follows code expressions for conventional concrete
- This is not *lightweight* concrete ($\lambda$=1)
- Typical unit weight ~135+ lb/ft$^3$




Source: FHWA

Data: Barrett et al. (2015)

# Tensile Strength



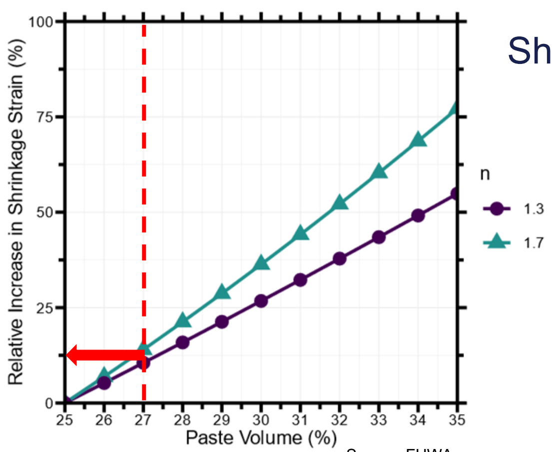

Source: FHWA

Data: Barrett et al. (2015)

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



# Shrinkage Considerations




Source: FHWA

Shrinkage is a paste volume property

*Pickett's Eq. for concrete shrinkage strain*

$$\varepsilon_c = \varepsilon_p(1 - V_A)^n$$

$\varepsilon_c$: shrinkage of concrete

$\varepsilon_p$: shrinkage of paste

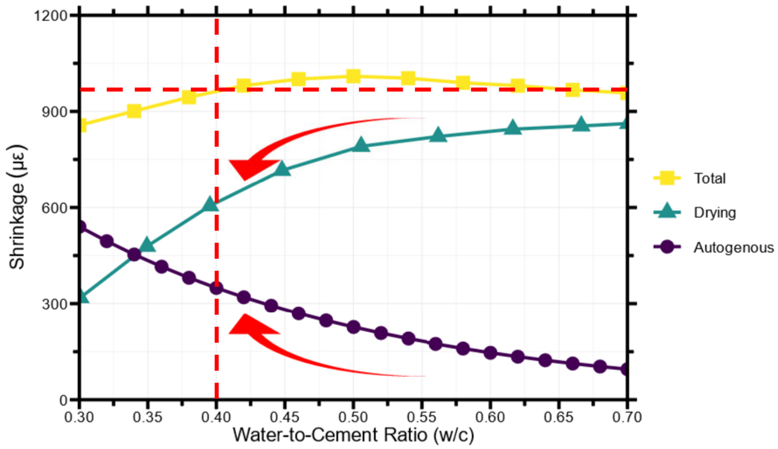
$V_A$: volume fraction of aggregate

$n$: 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:

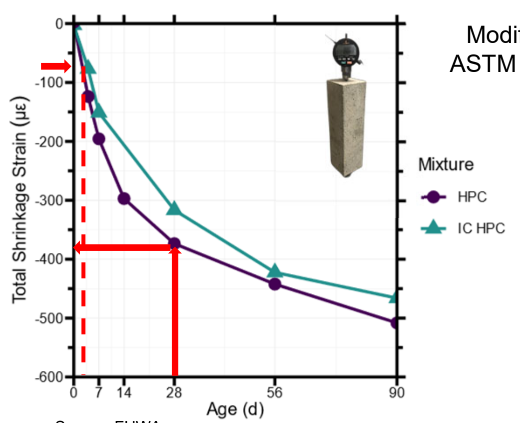



Source: FHWA after Weiss (2022)

Data: Neville (1995) & Rasoolinejad et al. (2019)



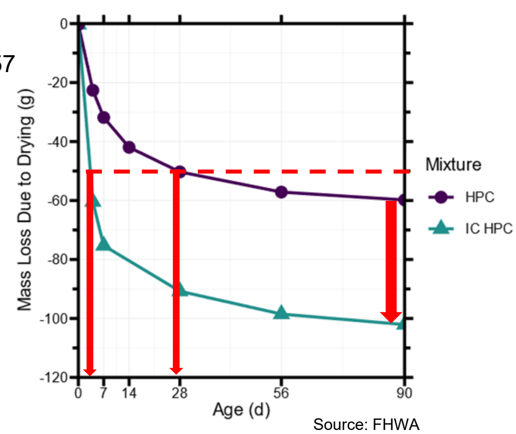
# "Drying" (Total) Shrinkage




Source: FHWA

Data: Barrett et al. (2015)

Modified ASTM C157

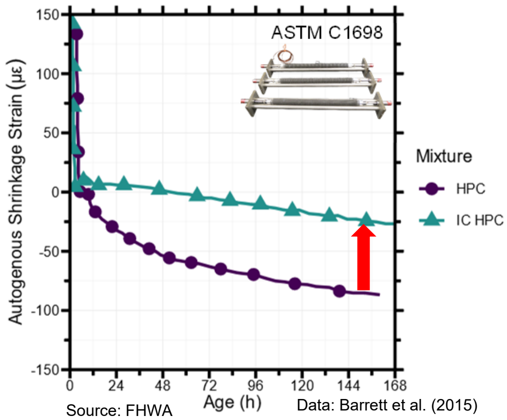



Source: FHWA

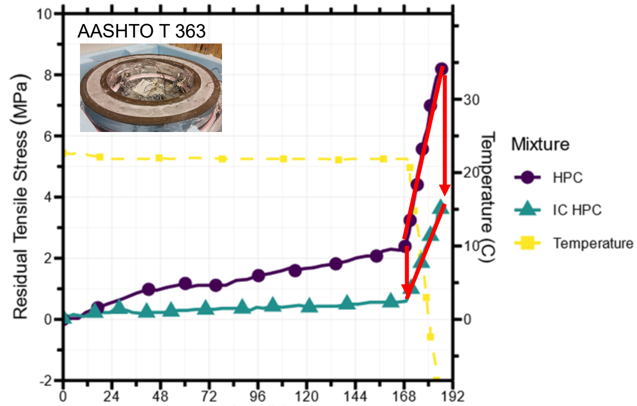
Data: Barrett et al. (2015)

Not a test that should be necessarily specified

# Autogenous Shrinkage




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



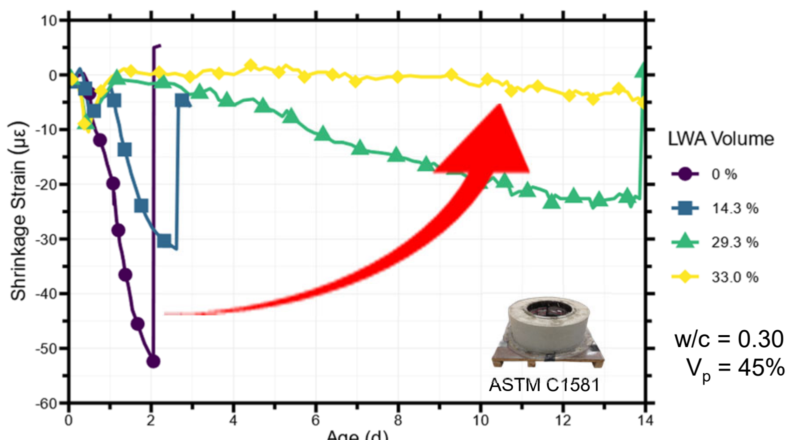

Source: FHWA Data: Barrett et al. (2015)

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




Source: FHWA Data: Henkensiefken et al. (2009)

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

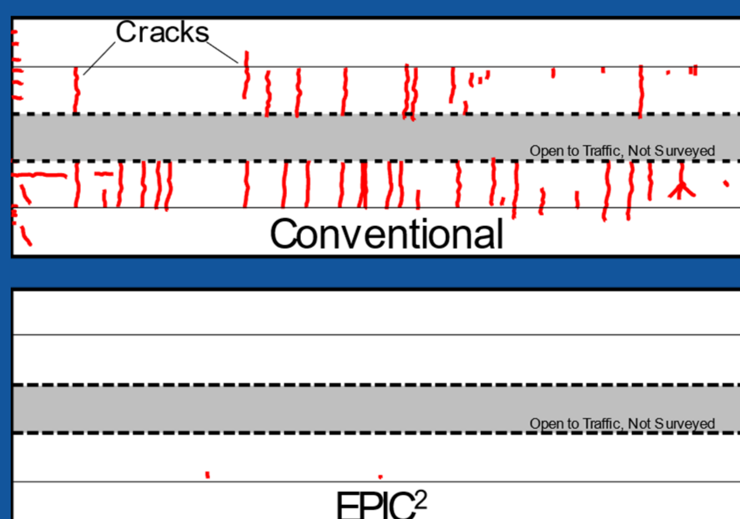
# Performance Relative to Shrinkage Reducing Admixtures?

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

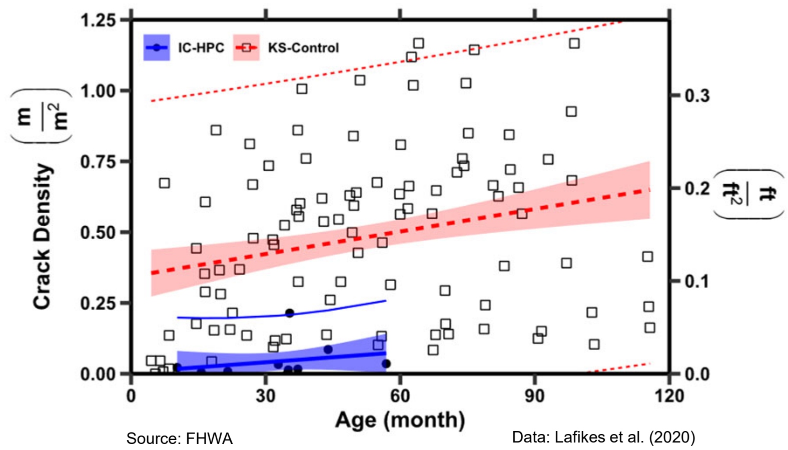



Source: FHWA

Data: Wang et al. (2019)

# Shrinkage Cracking Performance

Cracking Substantially Reduced




Source: FHWA

Data: Lafikes et al. (2020)

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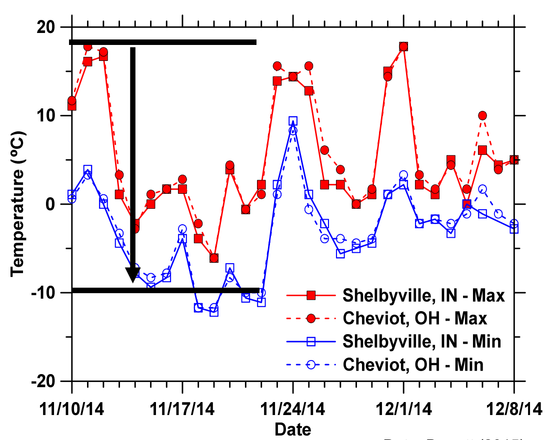
# Thermal Cracking Performance




Data: Barrett (2015)

All Image Sources: FHWA

Internal curing lowers the coefficient of thermal expansion

Higher resistance to thermal cracking

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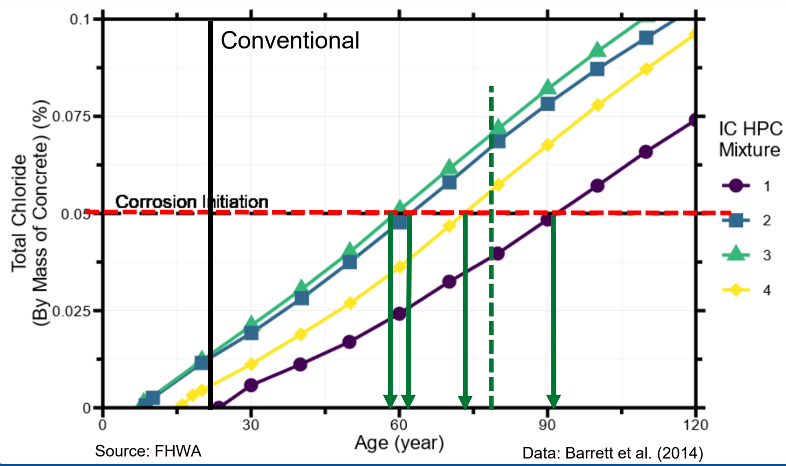
## Estimated Service Life




Estimated Corrosion Initiation Service Life:

60-90 years
~3 to 4.5x increase

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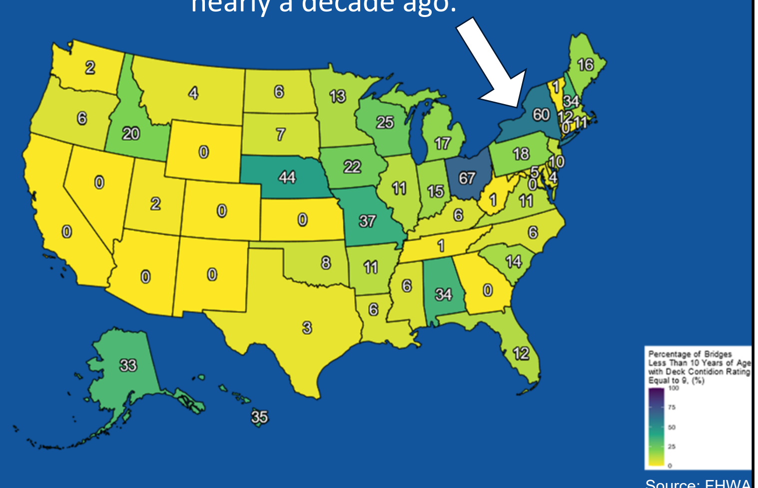
Percentage of Bridges,

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).

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# 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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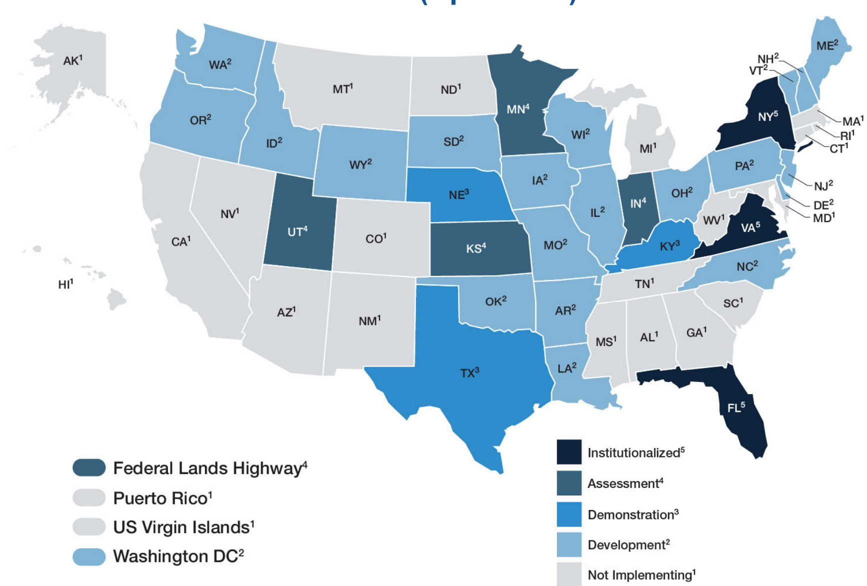
## Baseline (April 2023)

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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

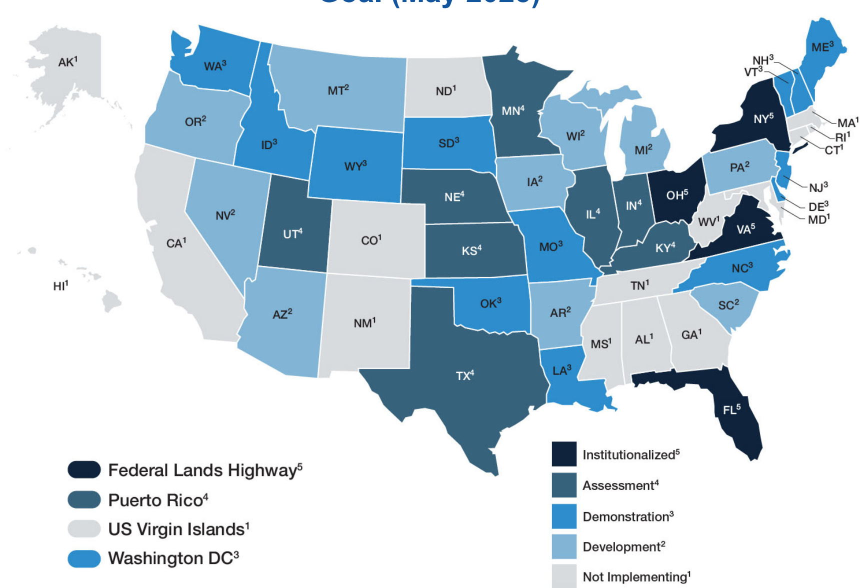
## Monitor
- Crack Inspections
- Post-Construction Remedial Work Occurrences
- Deck Condition Ratings

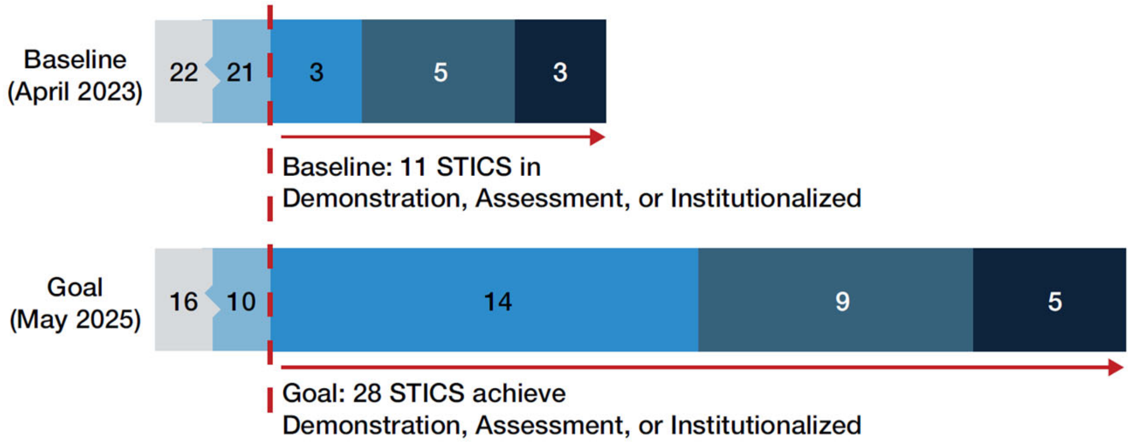
That Would Be:

EPIC$^2$



# Goal (May 2025)





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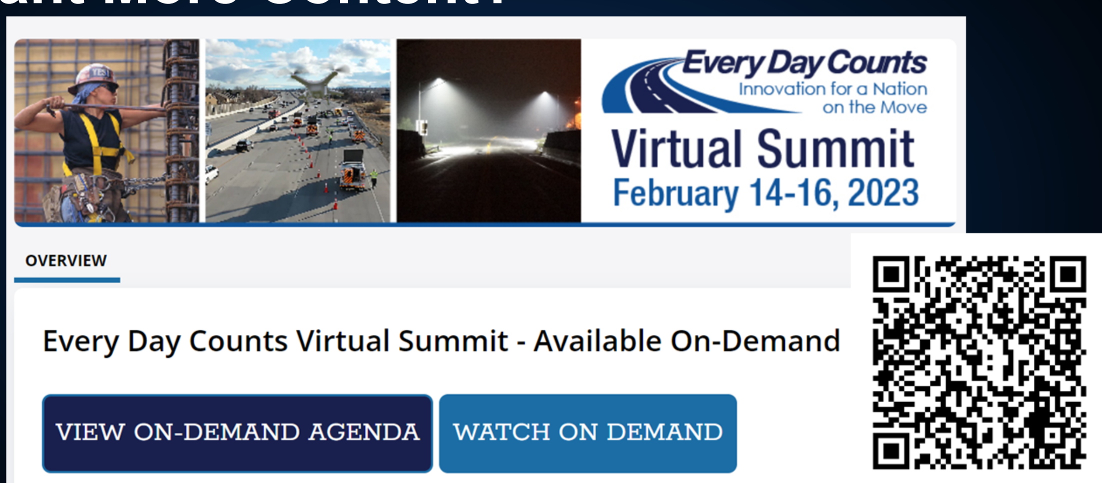


fhwa-everyday-counts-7-virtual-summit.com

## On-Demand Webinars

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

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