Internal Curing Concrete in Pavements and Bridge Decks

National Concrete Pavement Technology Center

Tech Center

IOWA STATE UNIVERSITY

Institute for Transportation

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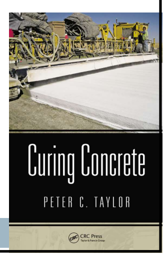
Internal Curing - Why

- Curing is:
  - ➢ Provision of moisture and temperature to allow hydration and minimize dimensional change
    - ➢ Keep it wet
    - ➢ Keep it warm
    - ➢ Start early, stay late



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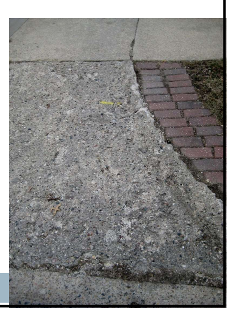
Internal Curing - Why

- Without curing we will increase risk of
  - Cracking
  - Scaling
  - A soft surface
- What about strength?



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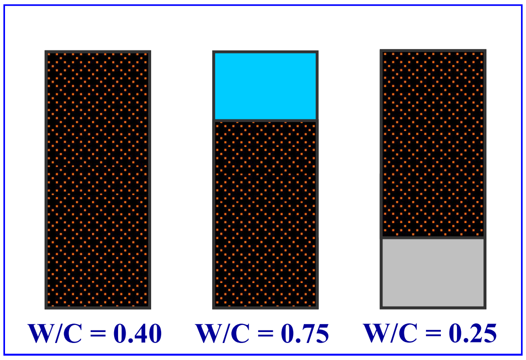

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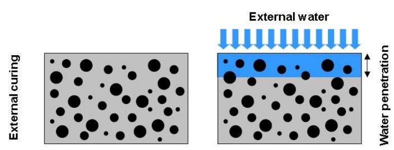
Internal Curing - Why



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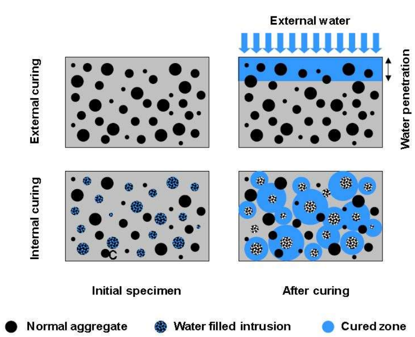
Internal Curing - Why



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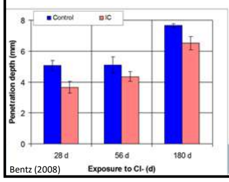
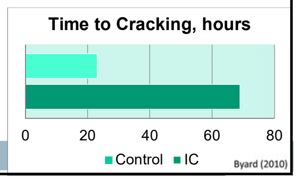
Internal Curing – So What?

- Reported Benefits
  - Less shrinkage, cracking, warping
  - Better hydration & SCM reaction
    - Improved durability
  - Extended service life





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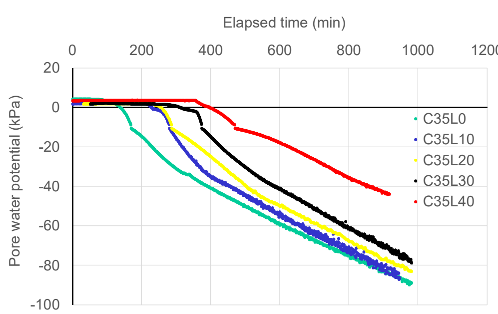
Pore Water Potential



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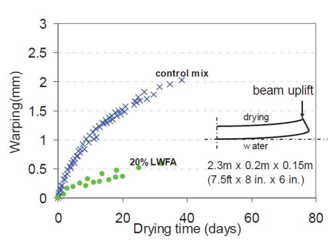
Internal Curing – So What?

- Reduced Warping
  - Thinner sections
  - Keep joints out of wheel path



Wei (2008)

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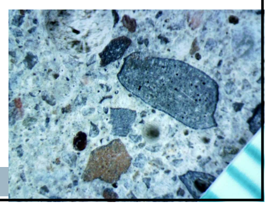
Internal Curing - How

- Material should
  - Hold sufficient water
  - Hold the water until needed and not effect w/c
  - Give up water at high RH (desorption)
  - Not adversely effect the concrete quality



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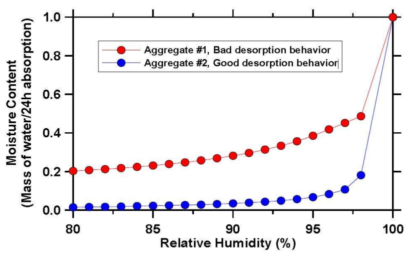
Internal Curing - How

- Desorption



Virtually all moisture available at 94% RH

Castro 2011

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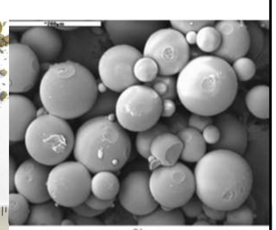
Internal Curing - How

- Expanded fine aggregate
- Super Absorbent Polymers

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How Much?

$$M_{LWA} = \frac{C_f * CS * \alpha_{max}}{S * \phi_{LWA}}$$

where

M_{LWA} = mass of (dry) LWA needed per unit volume of concrete (kg/m³ or lb/yd³);

C_f = cement factor (content) for concrete mixture (kg/m³ or lb/yd³);

CS = chemical shrinkage of cement (mass of water/mass of cement);

α_{max} = maximum expected degree of hydration of cement (0 to 1); For ordinary Portland cement, the maximum expected degree of hydration of cement can be assumed to be 1 for $w/c \geq 0.36$ and to be given by $[(w/c)/0.36]$ for $w/c < 0.36$.

S = degree of saturation of aggregate (0 to 1);

Φ_{LWA} = desorption of lightweight aggregate from saturation down to 93 % RH (mass water/mass dry LWA).

Or… about 7lb IC water for 100 lb cement

Bentz & Snyder (1999), Bentz, Lura, & Roberts (2005):

Construction

- Proper amount of water
- 30% replacement of fine aggregate
- Minimum 15% absorbed moisture
- Place under sprinkler for minimum of 48 hours
- Allow stockpiles to drain for 12 to 15 hours immediately prior to use

Internal Curing - How

- Can we do without this?
- Nope
  - Still have to keep the surface hydrating
  - That's where the abuse happens

Does it Work?

- 4 Projects
  - 3-span bridge in IA
  - Sidewalk at ISU
  - County pavements IA
  - Highway bridge deck OH

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Buchanan County

- Three span bridge at Pine Creek
  - One half conventional (both lanes)
  - Other half using Internal Curing Concrete
- About 20% (by mass) of fine aggregate replaced with light weight aggregate
- Other mix proportions unchanged

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Fresh Properties

	Field Samples		Lab Samples		Consultant Results	
	Control	IC	Control	IC	Control	IC
Slump, in	3.3	3.3	5.5	6.0	4.3	5.0
Air Content, %	7.5	6.5	7.4	7.0	6.5	6.8
Unit Weight, pcf	141.0	138.5	141.2	138.0	143.1	138.2
Initial Set Time, minutes			214	220		
Final Set Time, minutes			306	327		

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Hardened Properties

		Field Samples		Lab Samples		Consultant Results	
	Age (days)	Control	IC	Control	IC	Control	IC
Compressive Strength, psi	3	2848	2909	2410	2689	3810	3530
	7	4027	3969	3865	3739	4760	4820
	28	6653	6672	5968	6128	5910	7070
	56	7707	7838				
Splitting Tensile Strength, psi	3	339	336	298	342		
	7	454	435	412	429		
	28	556	486	522	538		
	56	637	582				
Modulus of Elasticity, ksi	3	3520	2990	3350	2890		
	7	3590	3150	3420	3100		
	28	4300	3950	4120	3850		
	56	4600	4350				
Surface Resistivity, kΩcm	3	7.0	6.6	6.4	6.6		
	7	9.8	9.2	9.2	8.6		
	28	22.6	22.8	20.9	26.5		
	56	33.3	32.2				
	77	41.1	45.6				
RCPT, Coulombs	28	2407	2166	1986	1778	1239	1090
Air Permeability Index	28	10.13	10.18	10.35	10.59		

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Hardened Properties

Surface Resistivity, kΩcm							
	Laboratory					Field	
Age (days	Field samples		Laboratory samples				
	Control	20% IC	Control	20% IC	30% IC	Control	20% IC
3	7	6.6	6.4	7.3	8.7		
7	9.8	9.2	9.2	10.6	12.6		
28	22.6	22.8	20.9	38.3	51.1		
56	33.3	32.2	31.2	57	74.4		
86	41.1	45.6	42.6			50.3	52.7
365						70.7	73.9

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Live Load Testing

- Soon after the bridge construction was complete
- One year post-construction

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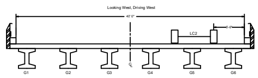
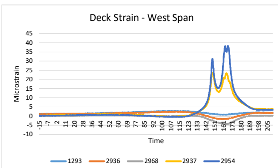
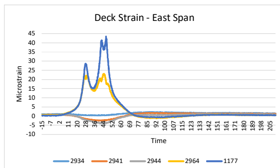
Deck Strains







IC

Conventional

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Post-Construction Site Visit

Conventional

IC

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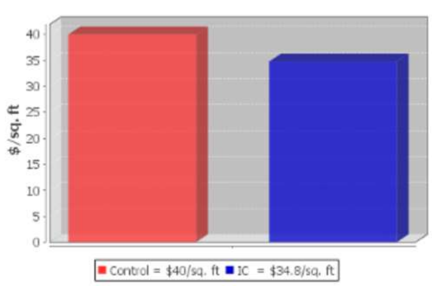
Life Cycle Cost



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Sidewalk on ISU Campus

- Warping
- Long term durability

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Concrete mixture designs

	Control concrete	Internally cured concrete
Portland Cement (type I/II, Ash Grove) (lb/cy)	457	457
Fly Ash (Oolagah, type C) (lb/cy)	114	114
Coarse Aggregate (lb/cy)	1698	1698
Fine Aggregate (lb/cy)	1375	942
Light Weight Aggregate (lb/cy)	0	200
W/C ratio	0.45	0.45
Air Entraining Agent (oz)	2.5	2.5

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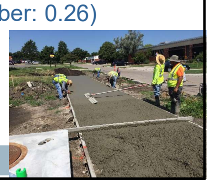
Fresh properties

- Control concrete:
  - Slump: 4''
  - Air content: 6.1% (SAM number: 0.31)
  - Concrete temperature: 90 °F
- Internal cured concrete:
  - Slump: 3''
  - Air content: 4.6% (SAM number: 0.26)
  - Concrete temperature: 87.7 °F



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Mechanical properties

	Tensile strength (psi)	Compressive strength (psi)	Modulus of Elasticity (ksi)
Control concrete	390	4785	5850
Internally cured concrete	387	5540	4900

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Surface resistivity

	Surface resistivity (kΩ.cm)				
	7-day	14-day	28-day	42-day	69-day
Control concrete	7.7	9.5	15.5	19.0	25.4
Internally cured concrete	7.9	9.6	16.6	20.6	28.0

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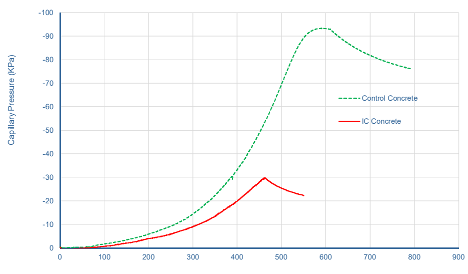
Pore water pressure



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Moisture

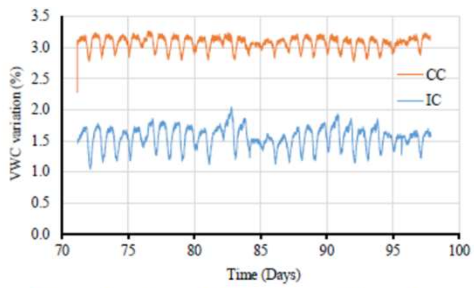

Figure 33. Variation in VWC between top and bottom layers

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Measuring warping

- Piano wire

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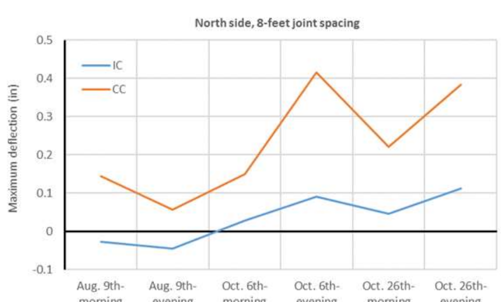
Warping



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Pavements

- Demonstrate constructability
- Assess benefits in the field
  - ➢Cracking risk
  - ➢Ride
- Monitor performance

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Pavement Demonstrations

- Build two sections ¼ mile long in 2 counties
- Only change to mixtures was replace 35% by volume of fine aggregate with LWFA from MO

	Control	Test
Cement	474	474
Fly ash	119	119
Coarse	1539	1539
Int.	0	0
Fine	1489	998
LWFA	0	321
H2O	255	255
Air		
Total	3876	3706

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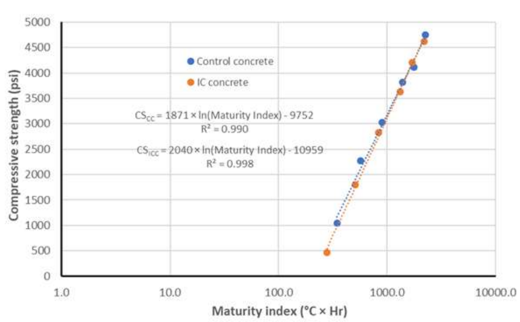
Maturity



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Lab Updated Results

Mixture	Slump	Air	Strength			MOE			Resistivity			
	in	%	psi			ksi			kohm.m			
			7	28	90	7	28	90	1	7	28	90
Washington IC	1.5	6.5	3130	4040	5807	3280	3650	4745	1.5	5.0	10.5	25.5
Washington NC	2.0	7.0	3100	3450	4817	3290	3710	4989	1.5	6.0	9.1	20.8
Winneshiek IC	2	6	3040	4634		2947	3785		2.0	8.2	16.9	
Winneshiek NC	1.0	6.5	3061	4597	6520	3008	3891	4972	2.0	8.8	16.0	32.5

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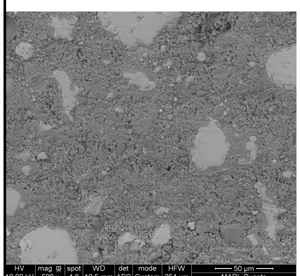
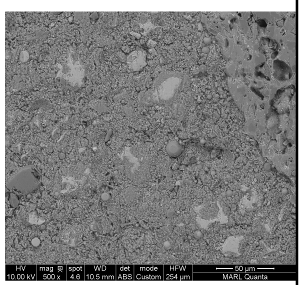
SEM



Plain



IC

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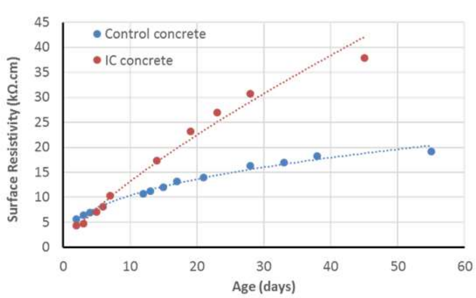
Transport properties



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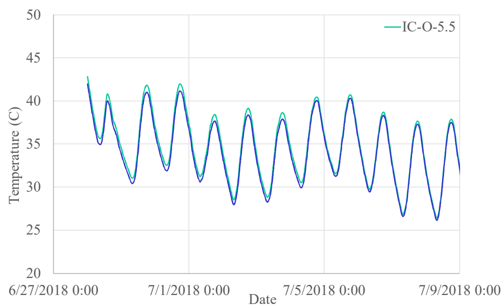
In-situ Temperatures



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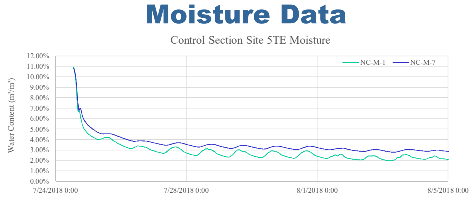
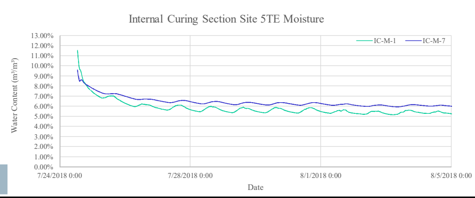
Moisture Data





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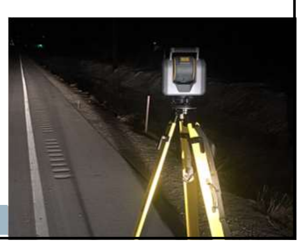
Warping

- Using LIDAR
- Measure when it is
  - ➢Hot and cold
  - ➢Wet and dry



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Washington LIDAR Feb 2019

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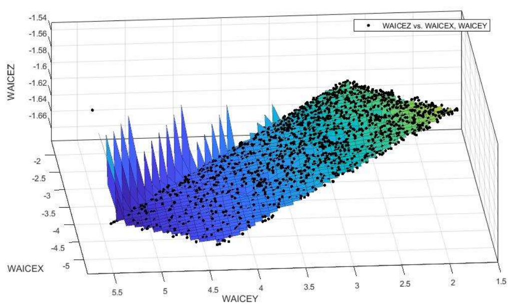
Washington LIDAR Feb 2019



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Washington LIDAR Feb 2019

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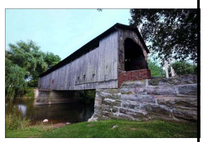
OH Bridge Deck

- Improve Asset Management by
  - Reducing the need to replace bridge decks with an ODOT specification for extended life bridge decks, using
    - Internal curing and/or
    - Other high performance concrete technologies

Old Fort, 1842, The Blade 9/23/2007



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Defining Success

- Crack resistance
  - Differential drying
  - Strength control
  - Modulus of elasticity
- Cold weather resistance
  - Impermeability
  - Air void system
- Corrosion of reinforcing
  - Impermeability

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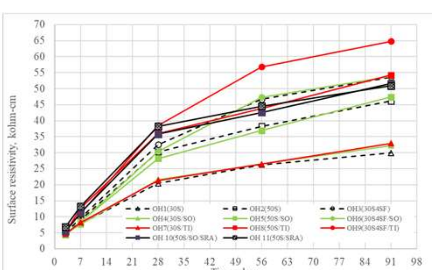
Lab Results

- Resistivity



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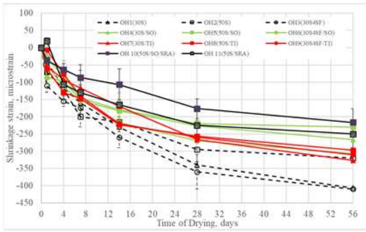
Results

- Hardened properties
  - Drying shrinkage – ASTM C157 (7 days wet storage)



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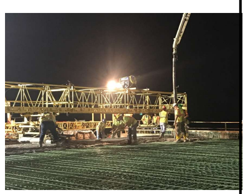
Field Trials

- Built conventional and internally cured bridge decks
- Measured properties of concrete mixtures
  - Mechanical properties
  - Temperature
  - Permeability
  - Shrinkage
  - Plastic shrinkage cracking risk



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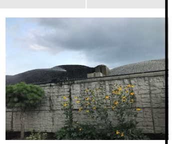
Construction

- Mixture proportions

	Cement lb/yd^3	Slag lb/yd^3	Water lb/yd^3	Sand lb/yd^3	LWFA lb/yd^3	Coarse Agg. 57 lb/yd^3	Coarse Agg. 8 lb/yd^3
Control concrete	410	160	256.5	1305	-	1360	355
IC concrete	282	282	253.8	940	220	1380	345



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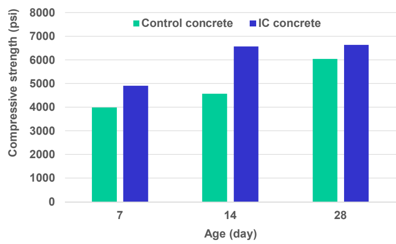
Hardened properties

- Field specimens
- Standard curing



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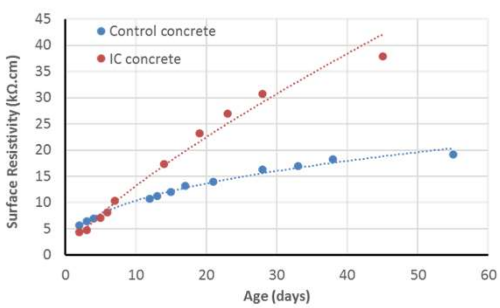
Transport



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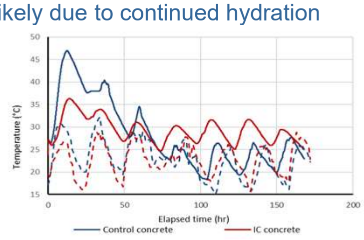
Embedded temperature sensor

- IC stayed warmer longer
- Likely due to continued hydration



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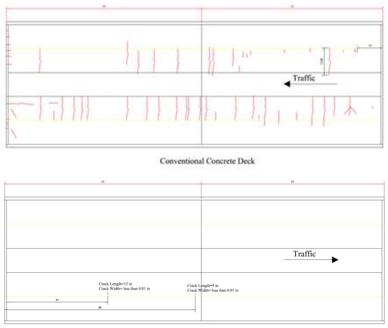
Cracking



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Closing

- Looks too easy…
  - ➢Need an extra stockpile
  - ➢It has to be wet
  - ➢Transport?
  - ➢Handling in the batch plant

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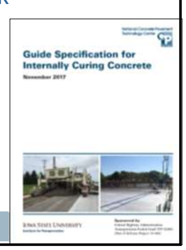
Closing

- Theoretically sound
- Some construction challenges
- Little change in structural performance
- Helps durability and cracking risk
- Recommended for
  - ➢Bridge decks
  - ➢Thin overlays

"Go do good things"



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