Causes of Concrete Bridge Deck Cracking and Suggested Measures to Eliminate Them

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Presentation Outline

- Problem Statement
- Causes of Bridge Deck Cracking
- Construction Practices
- Measures to Reduce Deck Cracking
- Recommendations

Full Depth Deck Cracks

Early age transverse shrinkage cracking is common for non post-tensioned bridges constructed after 1996

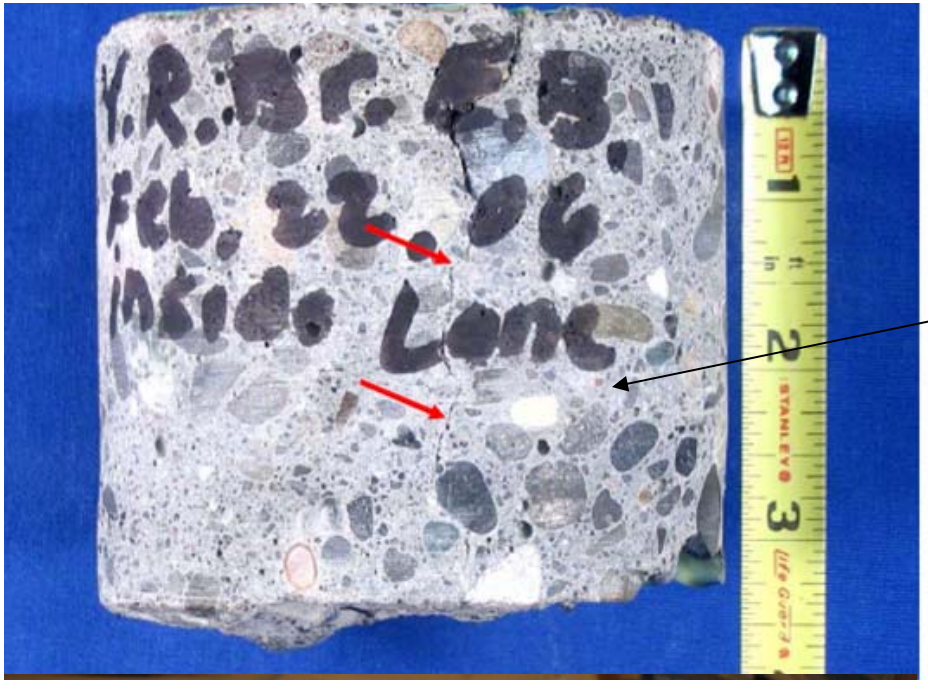
Cracks are typically at 2’ to 6’ spacing and are as wide as 0.013”

(Courtesy of WSDOT)

No Cracks in Older Bridge Decks

(Courtesy of WSDOT)

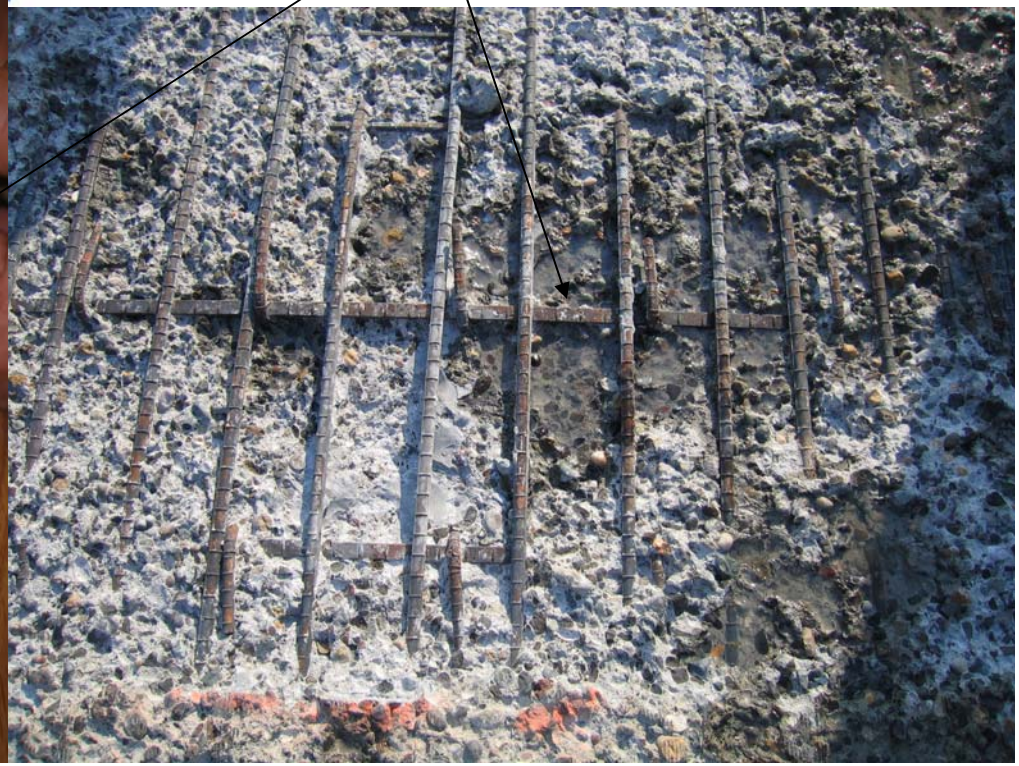
Concrete Mix Comparison



New deck mix

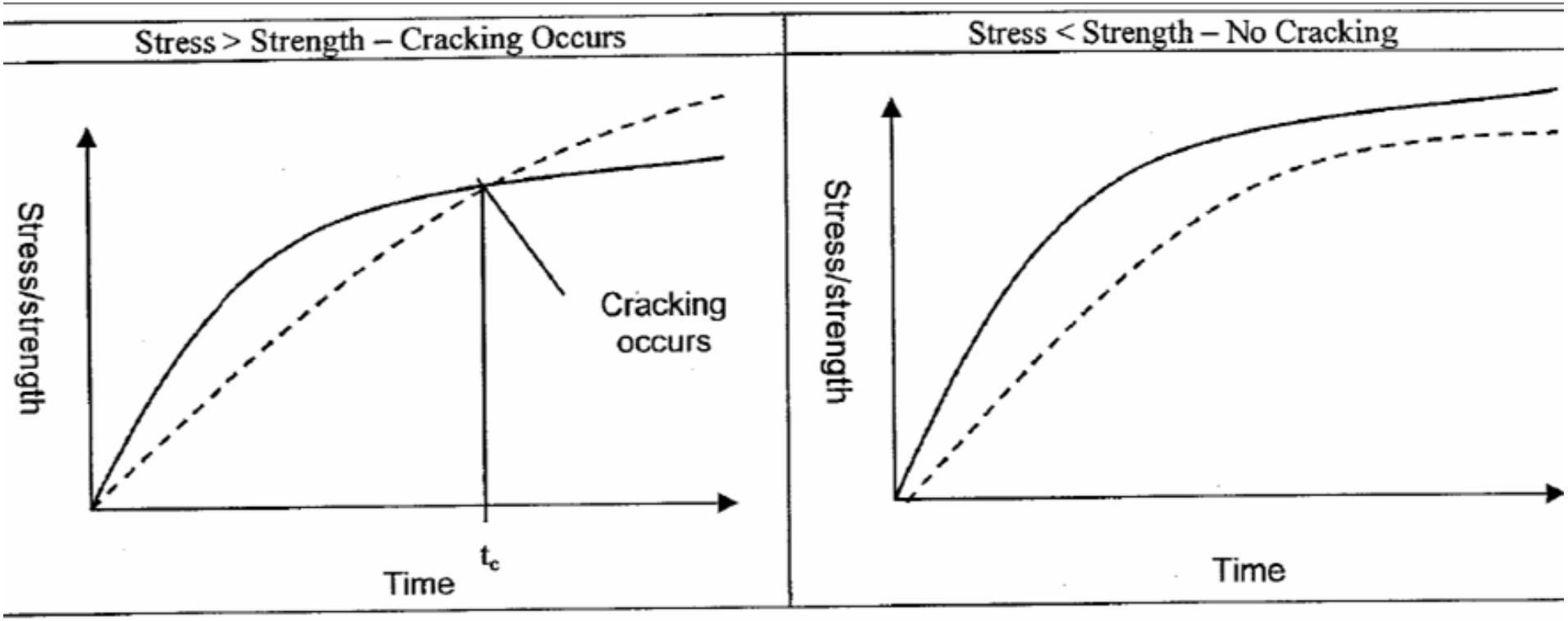
(3/4” nominal Max aggregate)

Old deck mix



Causes of Bridge Deck Cracking

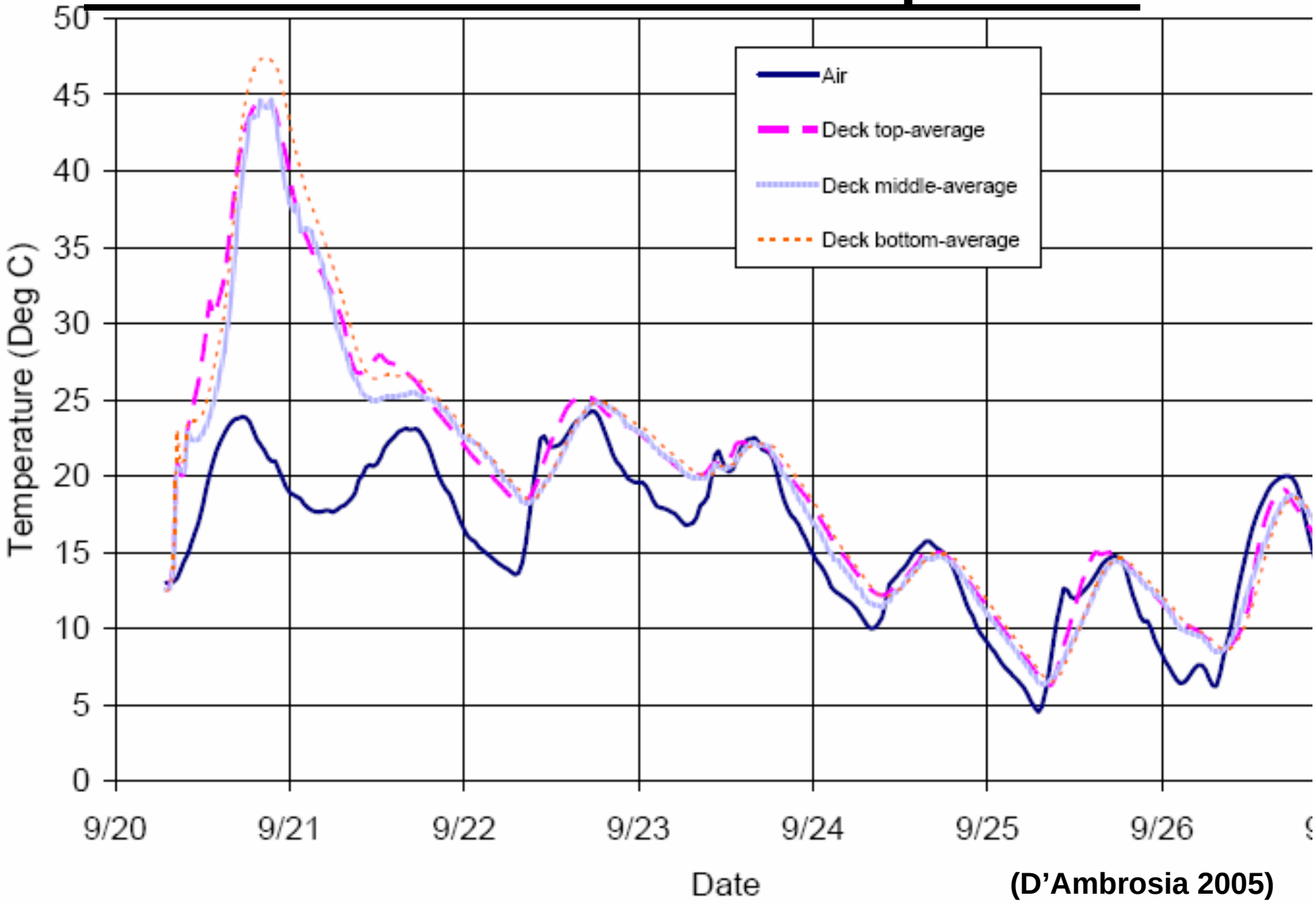
- Deck vs. air thermal differential
- Concrete shrinkage (drying, plastic, autogenous, carbonation)
- Flexural cracks
- Restraint mechanism
- Use of chemical de-icers
- Construction practices



Deck Cracking Tendency

(Delatte 2007)

Differential Deck vs. Air Temperature



(D'Ambrosia 2005)

Thermal Stresses

ε = Coefficient of thermal expansion for concrete (0.000006) (ΔT)

$\varepsilon = (0.000006)(54) = 324\ \mu\varepsilon$

Drying Shrinkage

- **Mix Volume Change Due to Loss of Water**

Mixes with free shrinkage > 400 micro-strain in 56 days are prone to early age cracking

(Nassif 2007)

Free Shrinkage Test

AASHTO T 160

(Courtesy of WSU)

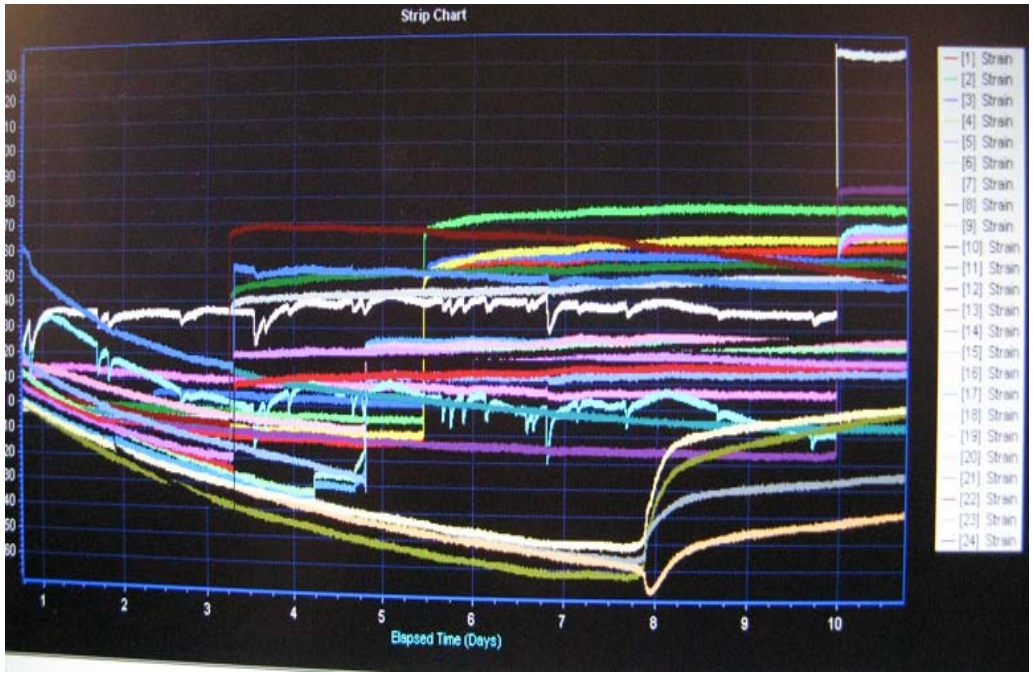
Ring Test

AASHTO PP34-99

Concrete Ring Test
WSU Laboratory

- Strain gages are connected to data acquisition system
- Time versus strain data are collected
- A sudden strain jump (reduction) of more than 30 microstrains (30 με) indicates cracking in concrete

(Qiao 2009)



Autogenous Shrinkage

Inadequate presence of free water during hydration due to low w/cm ratio.

Can be as high as 250 micro strain

(AASHTO LRFD)

Carbonation

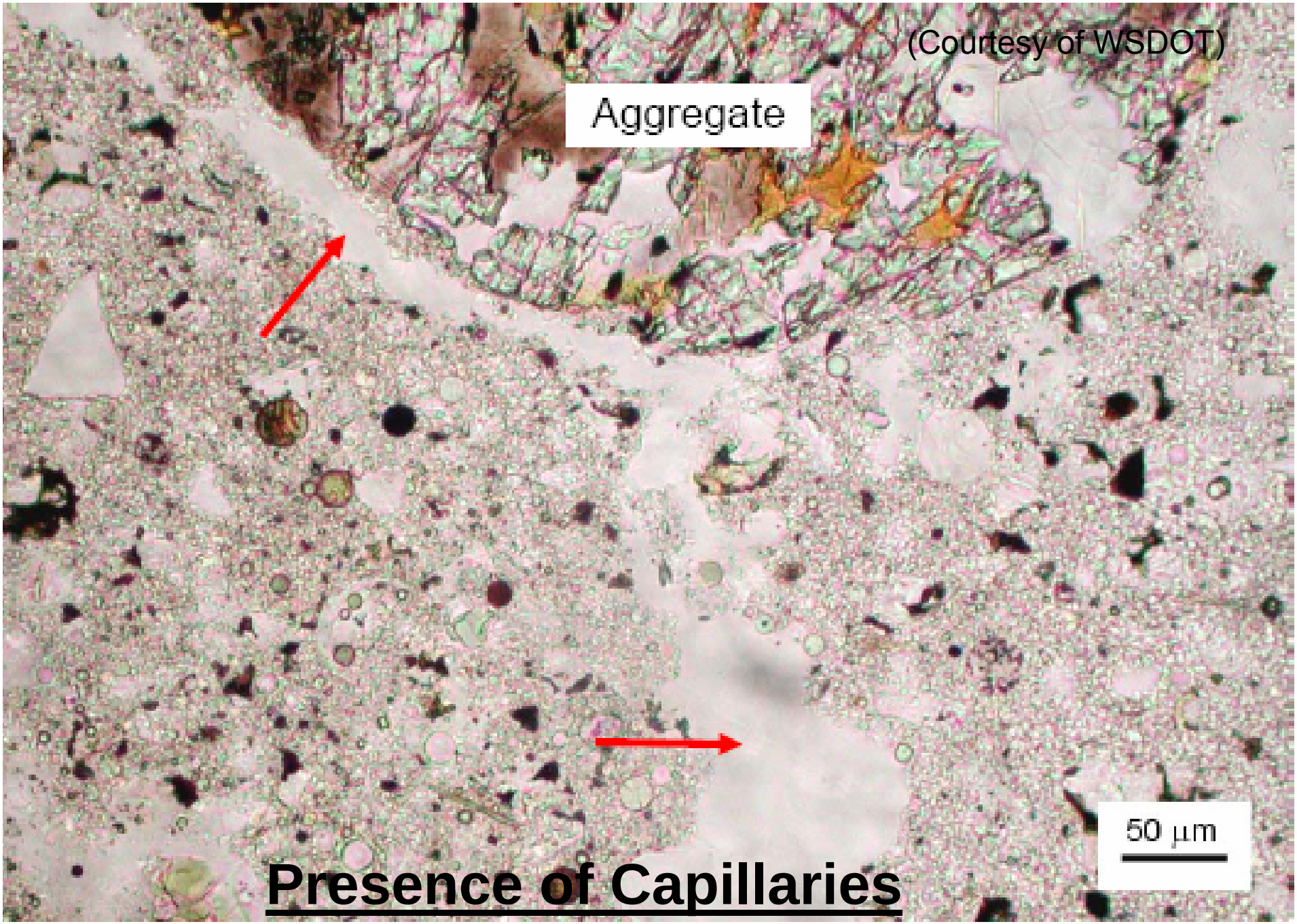
$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$

Hard calcium hydroxide is changed to soft calcium carbonate

Plastic Shrinkage

Rapid loss of bleed water resulting in map cracking

Courtesy of WSDOT



Presence of Capillaries

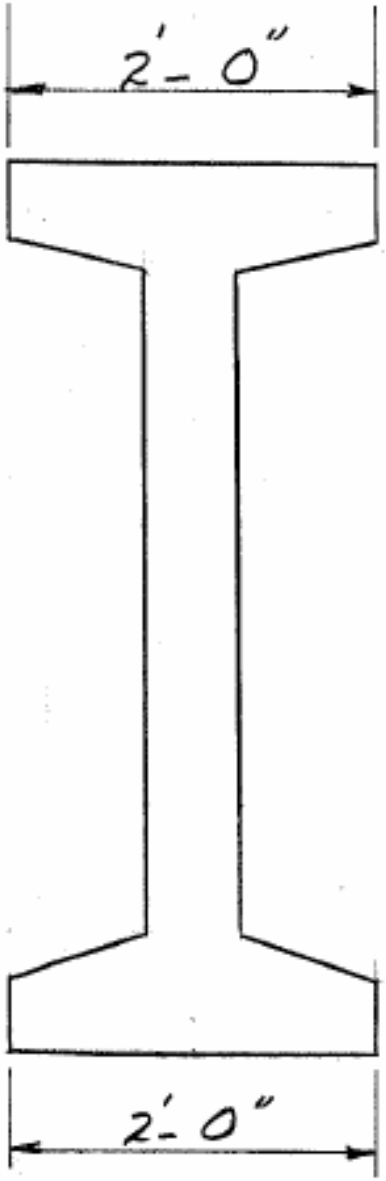
Flexural Cracks at Intermediate Pier

(Courtesy of WSDOT)

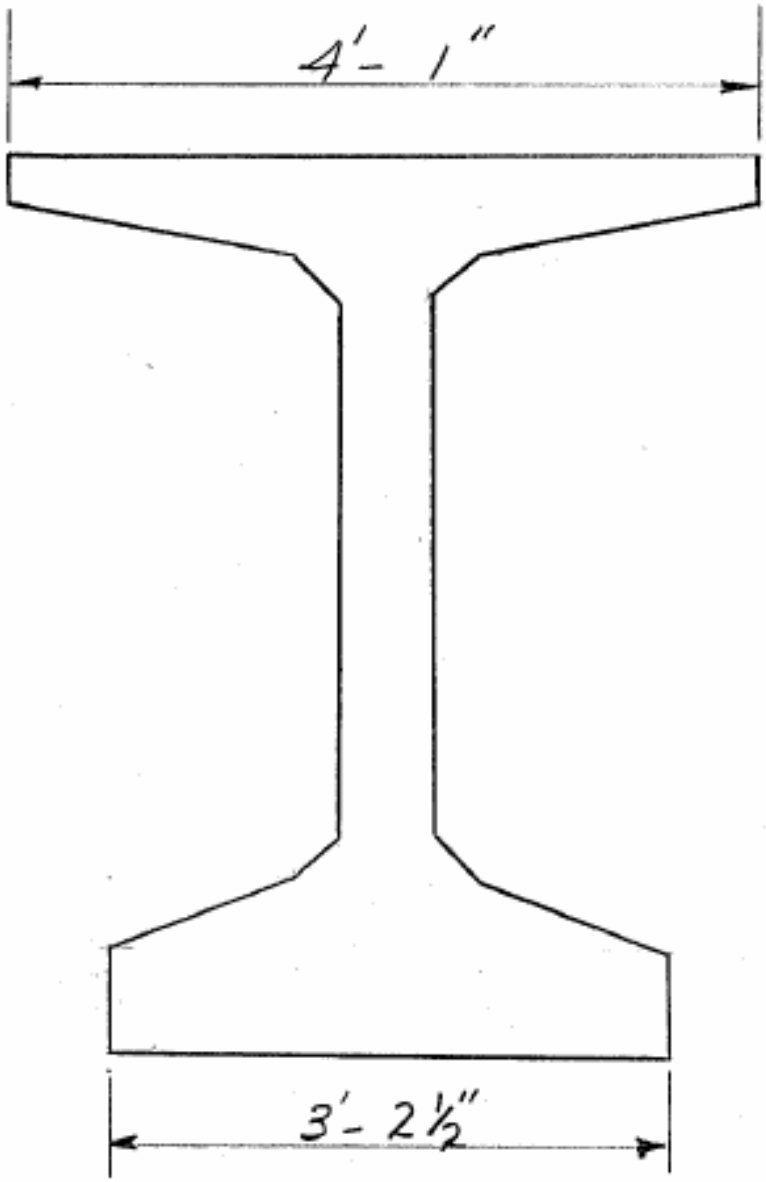
Restraint Mechanism

Shear studs and stirrups, as well as the girder top flange, provide restraint against deck thermal and shrinkage forces

The larger the restraint, the more likely deck will crack at an early age



Past WSDOT Girders



Current WSDOT Girders

Concrete Cover Over Deck Rebar

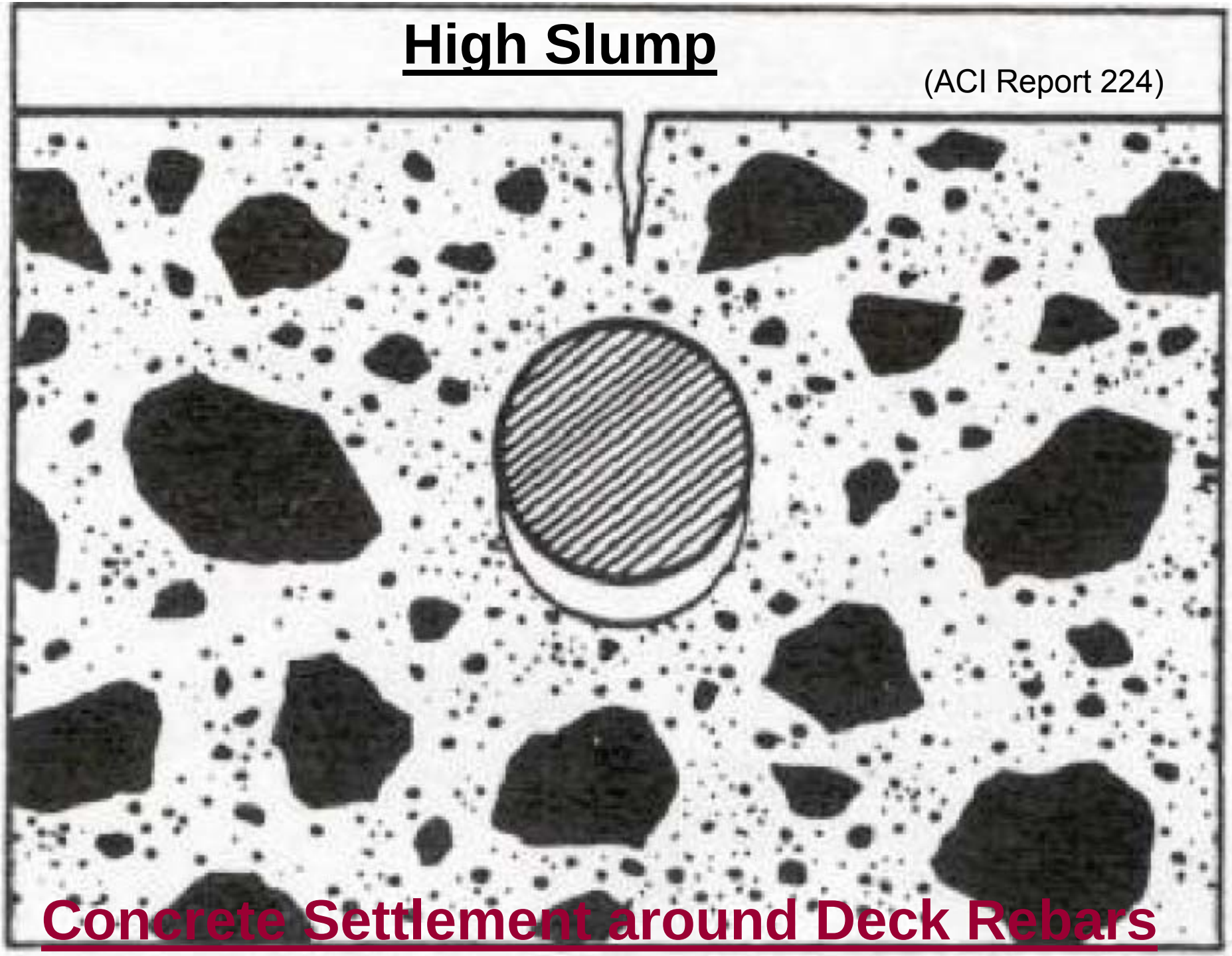
- Increased over the years to the current 2 ½”

Impact of Deicing Chemicals

Cylinders Exposed to MgCl2 After 84 Days (Sutter 2008)

High Slump

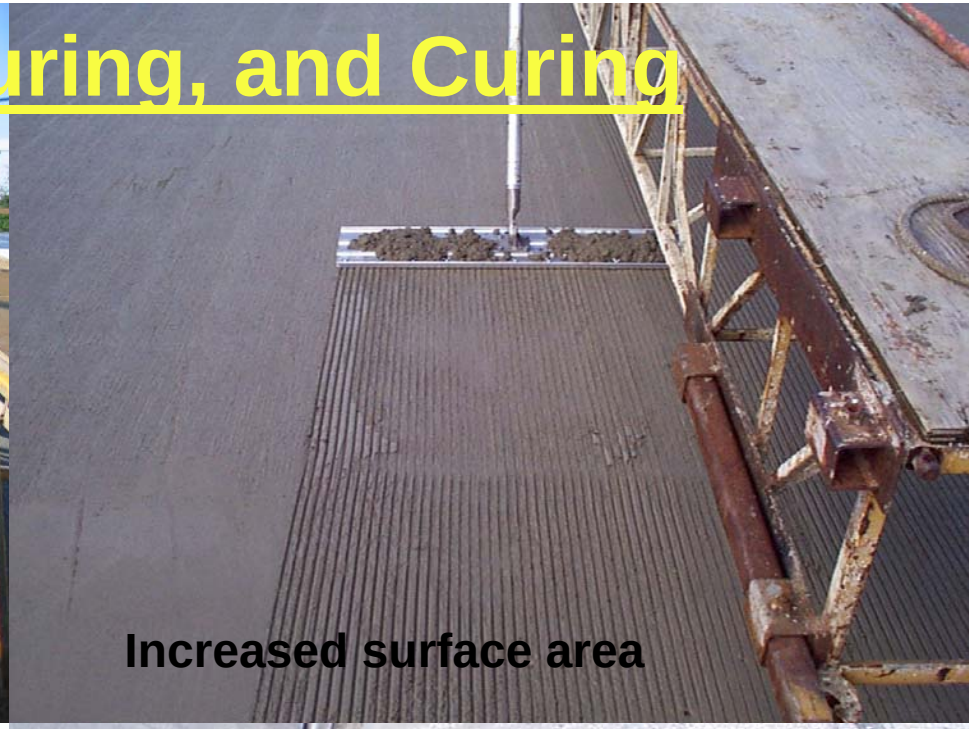
(ACI Report 224)



Concrete Settlement around Deck Rebars

Finishing, Texturing, and Curing

Deterioration of entrained air

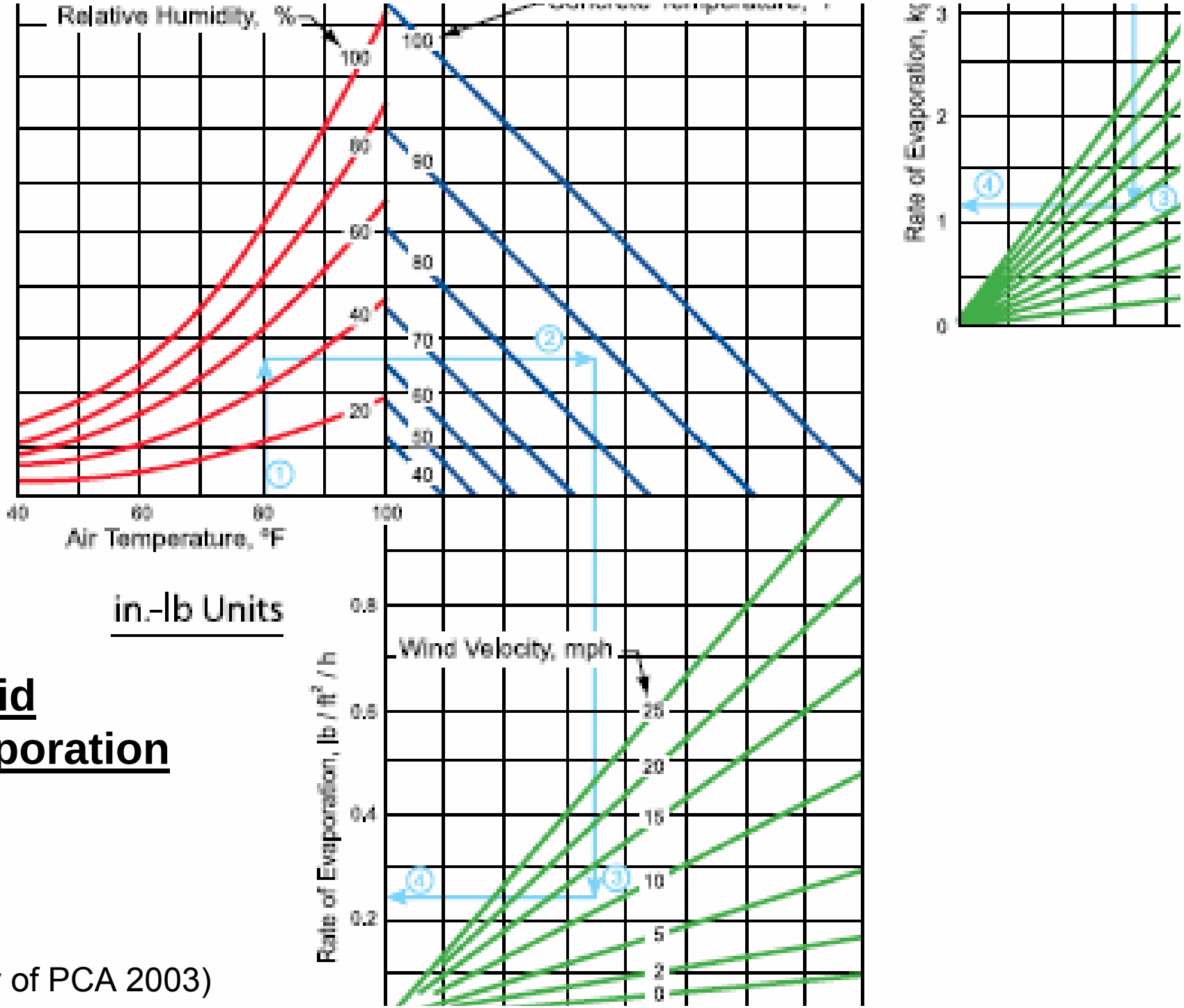


Increased surface area

Late application of curing Compound

Late start of wet curing

Rapid Evaporation



(Courtesy of PCA 2003)

Effective Measures to Reduce Transverse Bridge Deck Cracking

- Optimized concrete mix design
- Improved construction practices
- Design changes

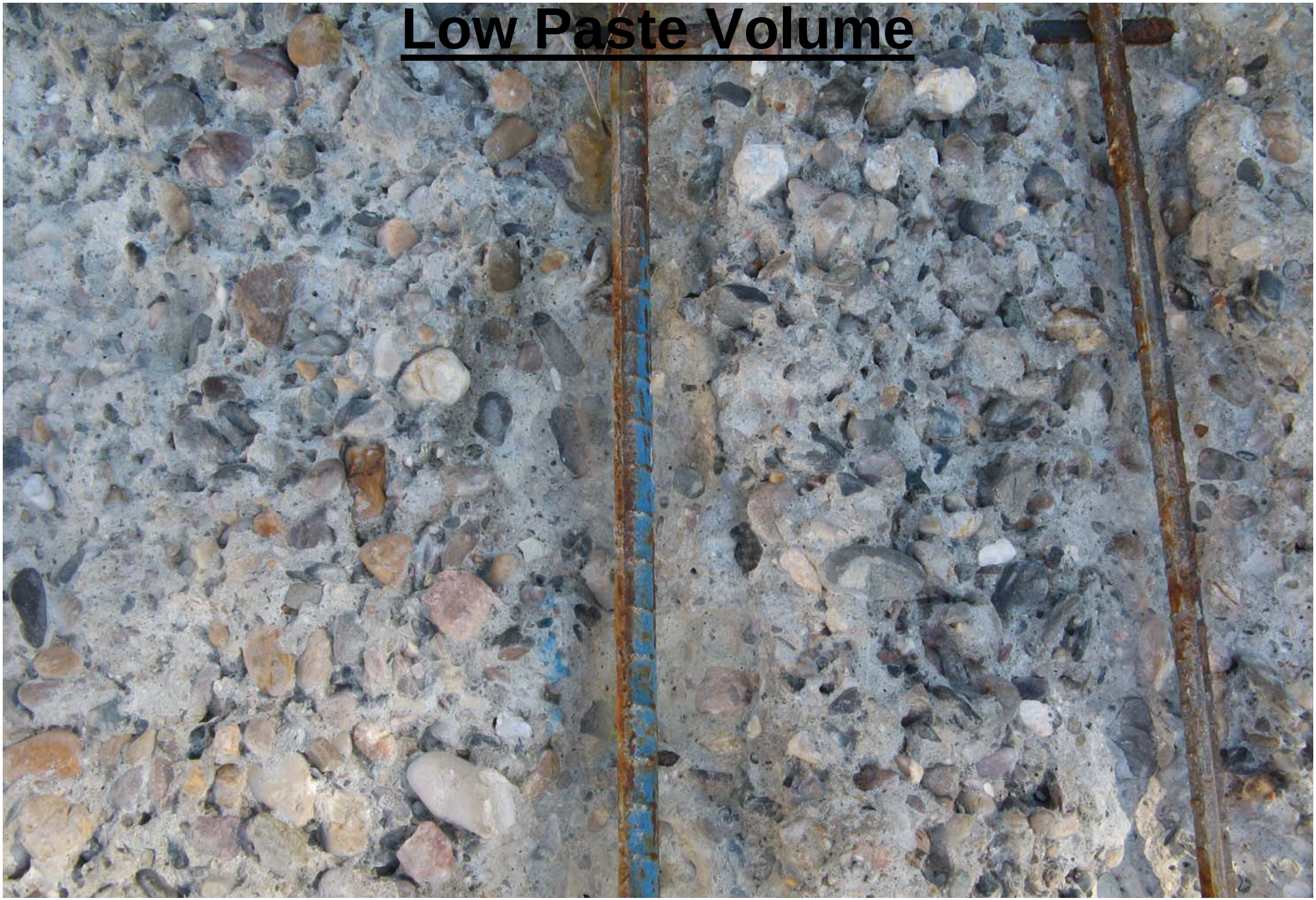
Specify Concrete Mix to Meet Desired Performance

- Shrinkage limit
- Temperature limits
- Permeability
- Freeze thaw
- Scaling resistance
- Abrasion resistance
- Flexural
- Air
- Slump
- Strength

Mix Design with Least Shrinkage
WSU Study

	Optimum	WSDOT Mix
Cement	462 lbs	660 lbs
Silica Fume	22 lbs	Fly Ash 75 lbs
CA	2,123 lbs	1,842 lbs
FA	1,087 lbs	1,096 lbs
Water	194 lbs	262 lbs
SRA	Uses	Not Used
Ring test	did not crack	Cracked
Shrinkage (28 days)	120 ue	420

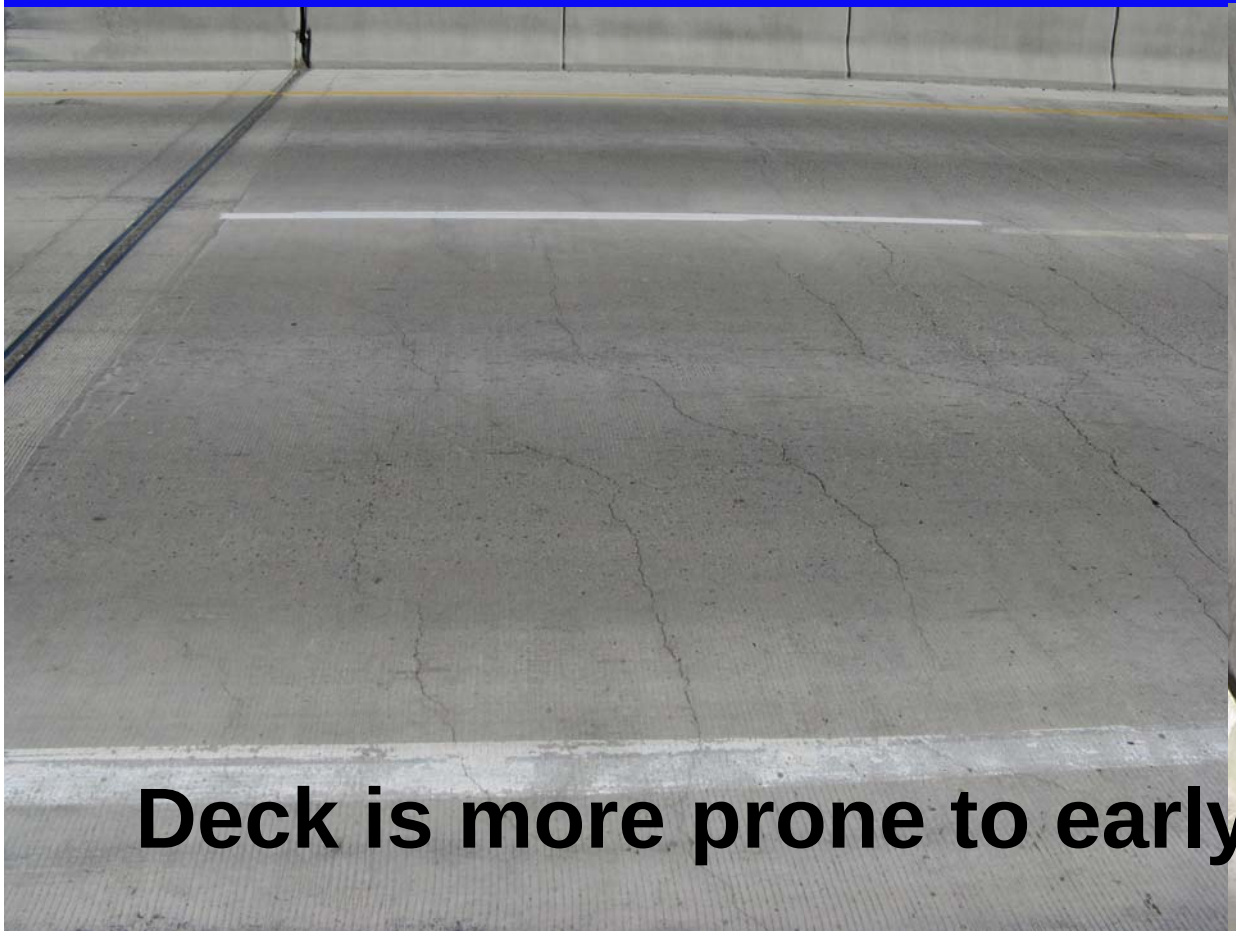
Mix Designed with Large Size Aggregates and Low Paste Volume



Slag Concrete Mix

- Less cracking intensity
- Tighter crack width
- Cracks not full depth

Fly Ash Concrete Mix



Deck is more prone to early cracking


Do Not Over-finish
Limit the number of passes to two


Do not Texture Wet Concrete
Diamond Groove Cured Concrete
(Courtesy of American Diamond Cutting)

Best Curing Practices

- Fog continuously
- Cover immediately
- Water cure 14 days
- Texture
- Apply 2 coats curing compound

Rebar Cover & Spacing

- **Reduction in rebar cover from 3” to 1 ½” has shown to reduce cracking by 19% and crack widths by 13% (Curtis 2007)**

- **Use small bar sizes with close spacing**

No Cracks in Post-tensioned Structures

(Courtesy of WSDOT)

Recommendations

1. **Limit the paste content to < 25% of mix by volume** (Darwin 2007)
2. **Increase the nominal max Aggregate Size to 1 ½”**
3. **CA/FA in excess of 1.48 or in excess of 1850 lbs of CA** (Nassif 2007)
4. **Use shrinkage reducing admixtures (SRA)** (Qiao 2009)
5. **Limit thermal differential between concrete and ambient temp to 22 F** (Aktan 2003)

Recommendations Continue

6. Type “K” and Type II (MH) have reduced shrinkage
7. Use of Fly ash w/o SRA is not recommended (Qiao 2009)
8. Limit fresh concrete temperature to 70 F
9. Fog continuously post finishing
10. Do not over-finish
11. Cover with soaked blankets immediately
12. Reduce rebar cover to 1 ½”
13. Use de-icing chemicals only if can accept consequences
14. Longit. post-tensioning closes all transverse cracks