David Evans and Associates Inc.

Washington State Department of Transportation

How to Specify and Construct Durable Crack Free Bridge Decks: Washington State Experience

Mark Gaines, PE

Washington State DOT

Mohammad Sheikhizadeh, PE

David Evans and Associates

Presentation Outline

- Identifying the problem
- Development of WSDOT’s performance spec.
- Implementation
- Summary of results
- Future opportunities – thermal differentials
- Conclusions and recommendations

The Problem

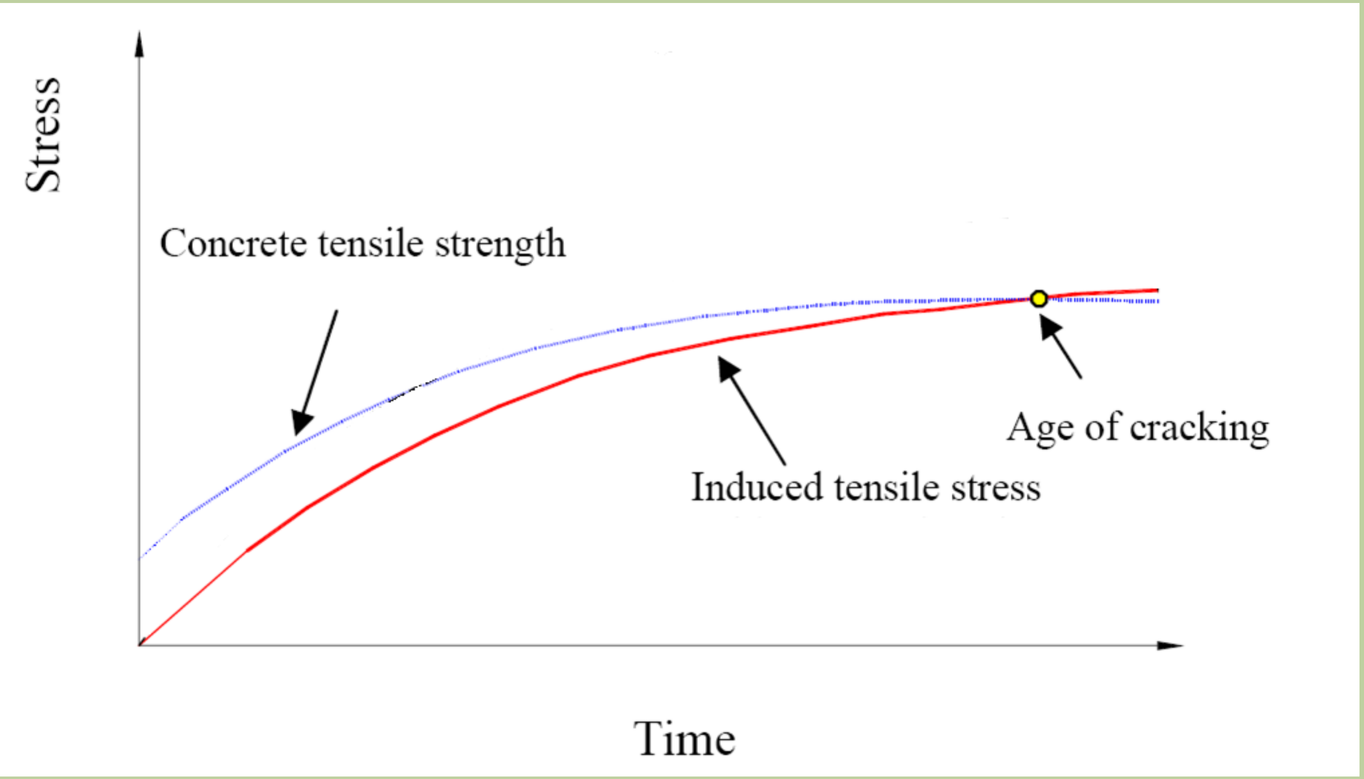
- WSDOT observed formation of transverse cracking in almost every bridge deck pour
  - Visible as soon as soffit forms were removed
  - Typically transverse, usually 3-6 feet on center
  - Independent of structure type, girder spacing, etc.

Typical Deck Performance

Manette Bridge, 2010

Causes of Bridge Deck Cracking

- Many factors involved, but essentially a shrinkage problem:



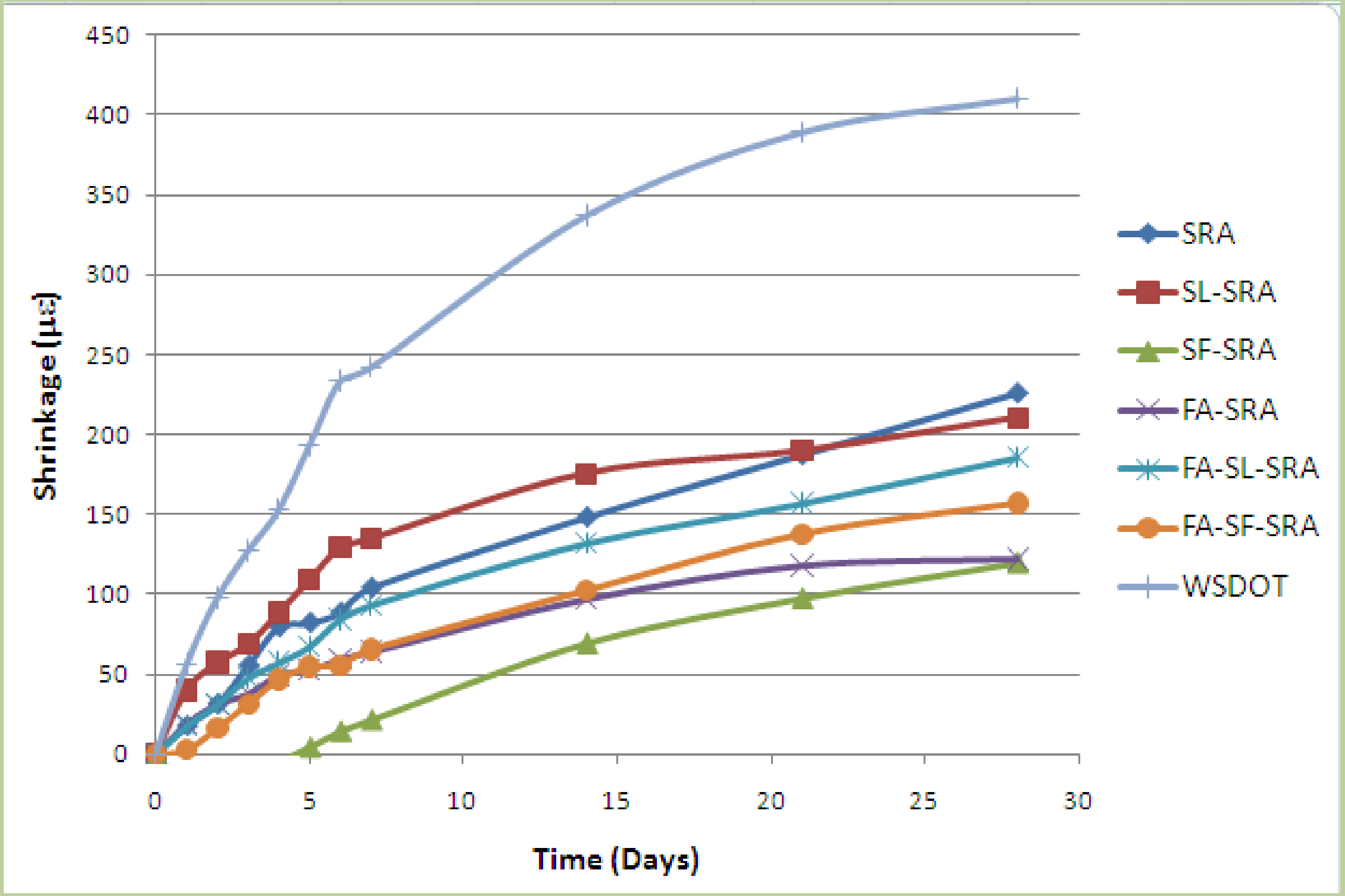
Mechanism of Cracking (from Neville 1996)

Evaluation of Concrete Mix Designs

- Brought in Washington State University (WSU)* to study the issue. Objectives:
  - Determine causes of shrinkage cracking
  - Identify mitigation strategies
  - Evaluate current WSDOT mix designs
  - Develop new mix deigns (with improved properties)
  - Provide recommendations on improved mix designs and practices.

* Dr. Qiao, Dr. McLean, and graduate student Jianmin Zhuang

High Performance Concrete Decks



Summary of WSU Recommendations

- Recommend use of SRA
- Limit use of fly ash
- Reduce paste volume
- Increase size of coarse aggregate
- Trial batches prior to production

Based on these recommendations, WSDOT developed a performance-based specification.

Mix Design Performance Requirements

- Summary of performance requirements
  - 28-day compressive strength: 4000 psi min.
  - Air content: 4.5% to 7.5%
  - Mix paste (cement + water) < 25% of tot. volume.
  - Nominal max. aggregate size: 1 ½”
  - Permeability: < 2000 coulombs at 56 days
  - Freeze-thaw Durability (optional)
  - Scaling: Visual rating ≤ 1
  - Shrinkage: <320 $\mu\varepsilon$ at 28 days

Concrete Placement

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Burlap Placement - Video

Concrete Placement

Establishing Wet Cure

Post-cure

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Diamond Grinding

High Performance Concrete Decks

- Full implementation starting August 2011.
- Cracking has been significantly reduced, but not eliminated.

Mix Design Properties

- Ten mix designs approved since 2009:

Property	"Old" Class 400D	New Performance Mix
Total cementitious (lb/cy)	735	590
Water/cement ratio	.34	.39
28-day comp. str. (psi)	7200	5990
Paste volume (%)	29	25
Shrinkage - ASTM C157 (microstrains)	410	260
Permeability (coulombs)	?	1460

SR16 EB and WB Projects

4000D deck cast 2010

Performance deck cast 2012

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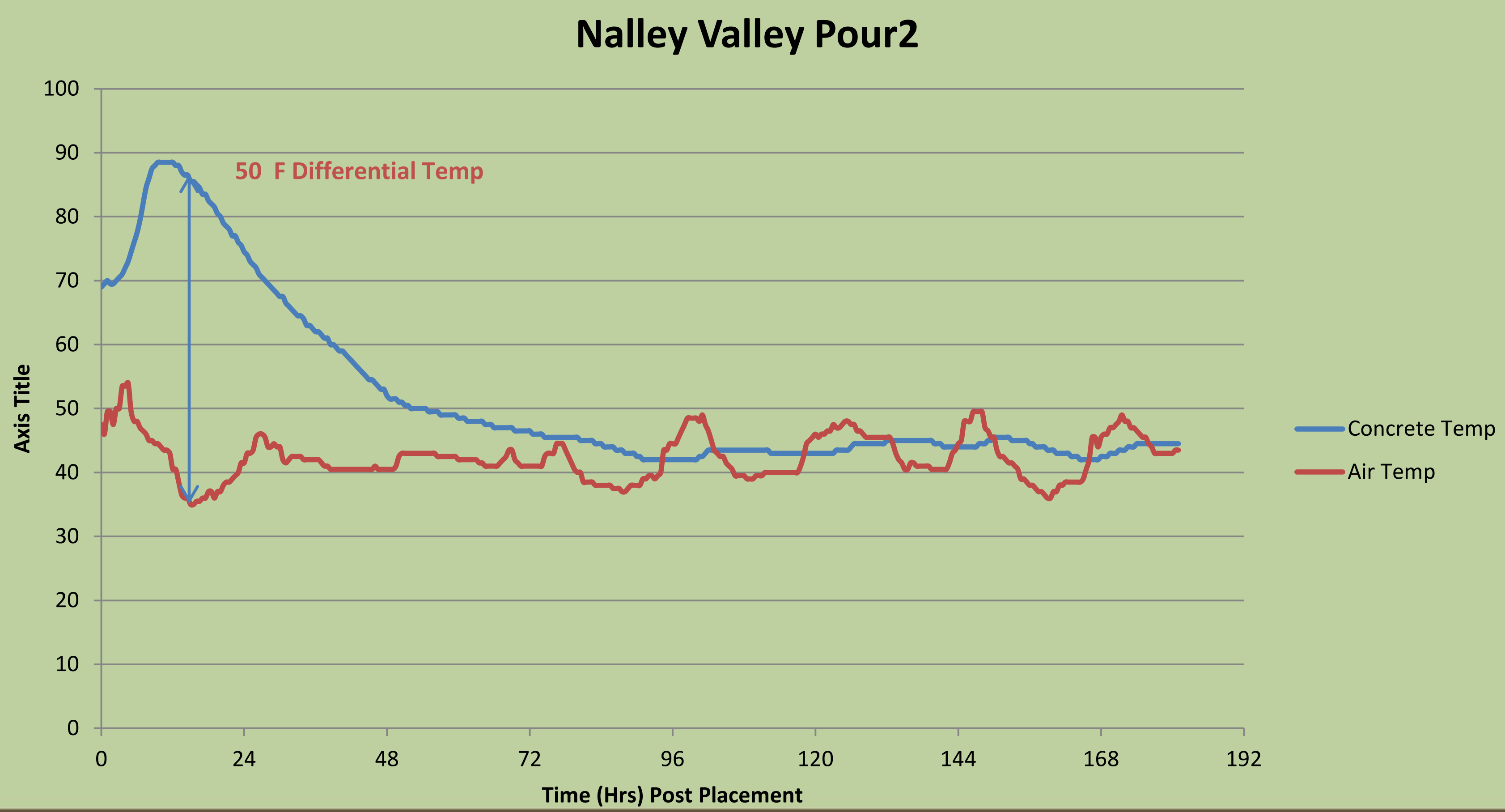
Effects of Temperature Differentials on Deck Cracking

Deck- Air Temperature Differential



Cold Weather Deck Heating

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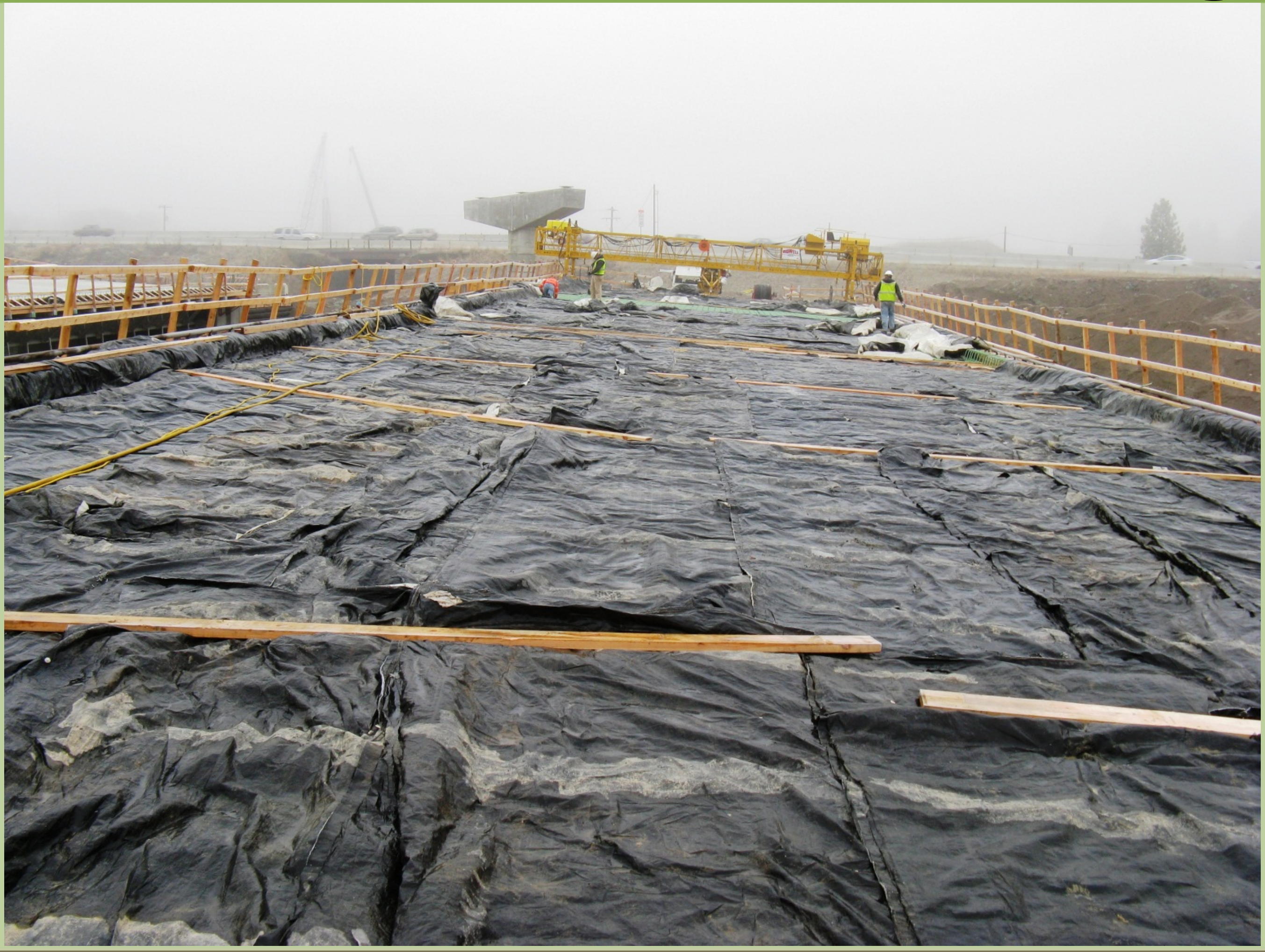
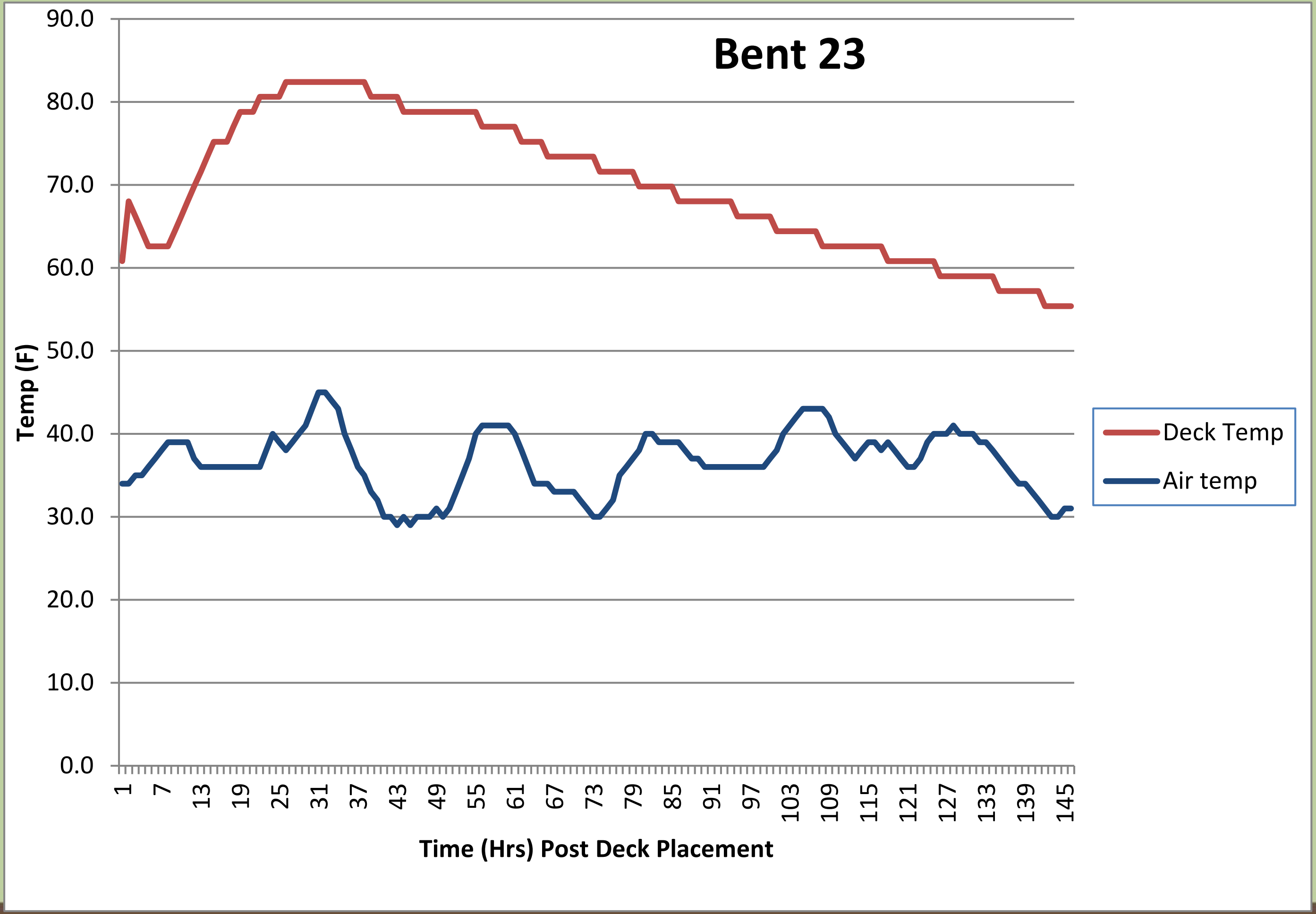


Heated Deck Hydration Signature



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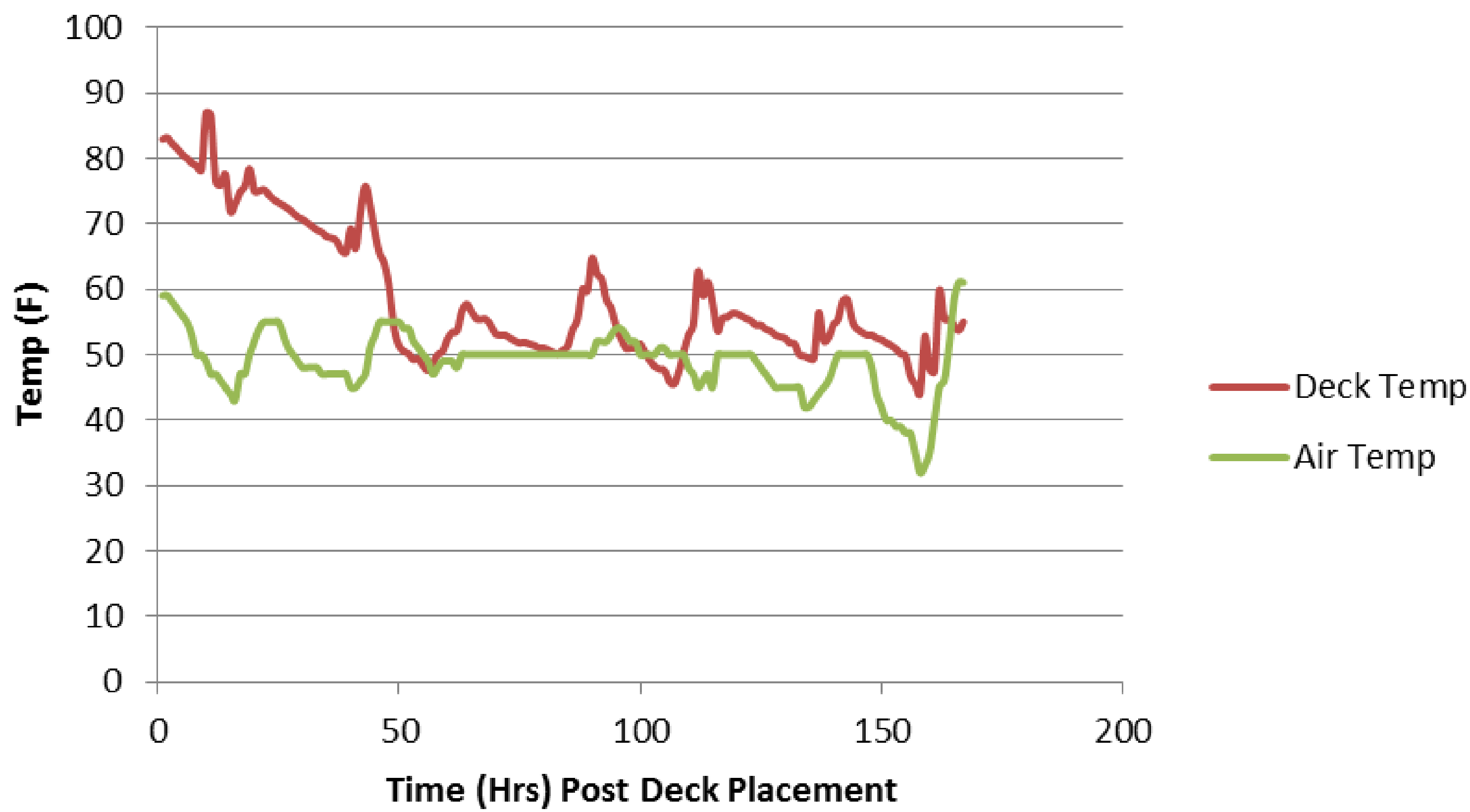
Bone River Bridge



Thermal Stresses

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

ε = (0.000006)(50) = 300 με

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

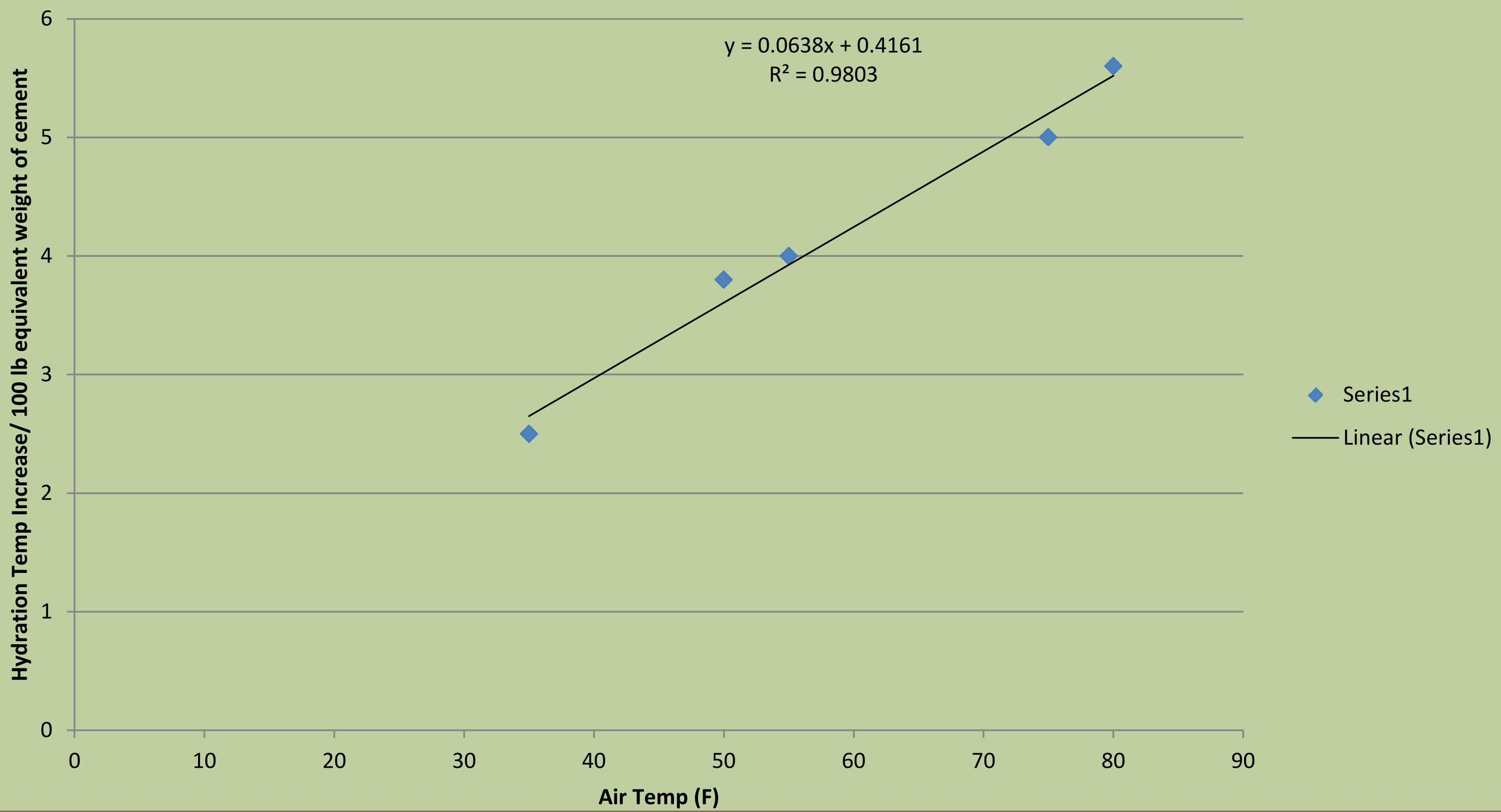
Performance Mix Designs

Ingredients	WSU	US 2	Spokane St	Bone R.	H3K	Nalley Valley
Cement	462	435	660	460	540	480
Fly Ash	0	130	131	150	0	85
Slag	0	0	0	0	115	0
Silica Fume	22	0	0	0	0	0
Water	194	220	240	232	242	215
CA	2123	1880	1760	2000		1930
FA	1087	1130	1180	1213		1265
Admixtures	Yes	Yes	Yes	Yes	Yes	Yes
SRA	Yes	Yes	No	Yes	Yes	Yes
Total Cementitious	484	565	791	610	655	565
Paste Volume	21%	25%	30%	26%	27%	24%
w/cm	0.4	0.39	0.3	0.38	0.37	0.38

Predicting Temperatures

- Estimate peak deck mix hydration temp
- Estimated time to reach peak temp

Estimating Concrete Mix Peak Hydration Temperatures



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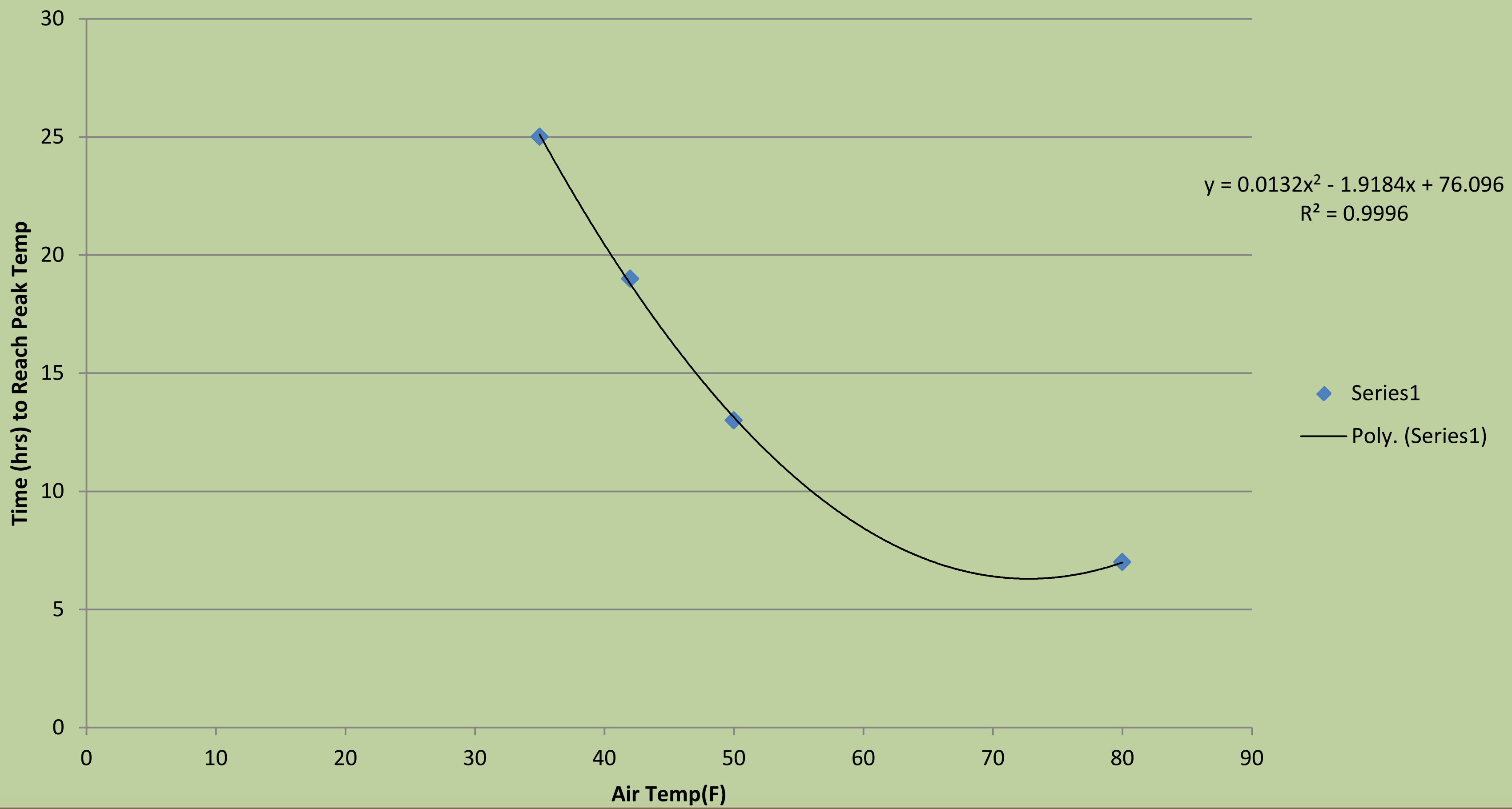
Predicting Time to Peak Temperature



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Limiting Peak Differential Temp

- Limit peak deck- air differential temperature to 24 F *
- Can be achieved through low-cost means
  - Timing of deck placement
  - Concrete mix temperature

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* Dr. Babai, 2003

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Conclusions and Recommendations

- WSDOT's new specifications have significantly reduced deck cracking, but have not eliminated it.
- Modifications to mix design, placement, curing and finishing operations have been made with no appreciable cost increase.
- Deck-air differential temperatures during curing in excess of 24 F is not desirable

Conclusions and Recommendations

- Peak hydration temps can be easily predicted based on mix design and curing temps
- Time to reach peak hydration temps should be predicted before deck placement
- Prolonged deck heating is counterproductive

Thank you!

Any comments?

Mohammad Sheikhizadeh, PE
Region Segment Manager
David Evans and Associates, Inc.
Mxsh@deainc.com
(360) 628-5005

Mark Gaines, PE
State Bridge Construction Engineer
Washington State DOT
gainesm@wsdot.wa.gov
(360) 705-7827