Investigation of Early-Age Bridge Deck Cracking for Caltrans

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CALTRANS’ concerns

- Annually spend nearly $50 million on deck rehabs – <u>Early-age deck cracking</u> is the usual culprit!
  - Structure work
  - Traffic management
  - Construction
- Approx. 90% of rehab jobs - Methacrylate (HMWM)
- Approx. 10% - Polymer concrete overlay

Summary of number of bridges with deck cracking 2000-2010

Year	# Years Post Construction	
	4	2
2000	96	87
2001	72	64
2002	55	41
2003	73	31
2004	43	27
2005	39	30
2006	31	24
2007	53	41
2008	44	36
2009		26*

What is early age-cracking?

- Occurs in first several months
- Transverse
- Through-deck
- 10 to 20 mils
- 1 to 3 m apart

- Plastic cracking
  - also a problem

Types of Cracking

- Plastic shrinkage cracking
  - Craze cracking
- Settlement cracking
- Autogenous shrinkage
- Thermal cracking
- Drying shrinkage

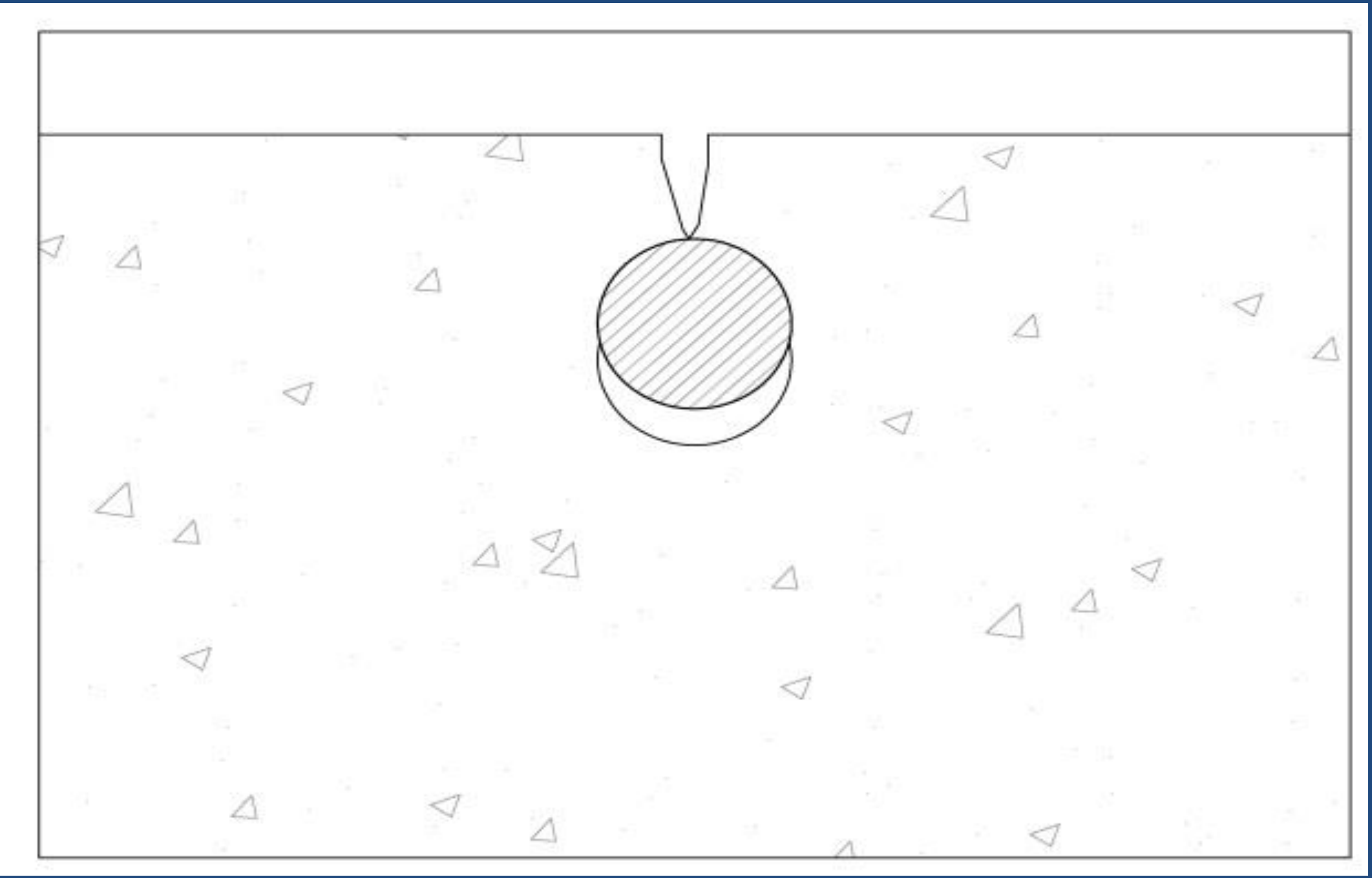
Plastic Shrinkage Cracking

Plastic Shrinkage Cracking

Plastic Shrinkage Cracking
Causes

- Inadequate curing
  - Delayed wet curing
- Susceptible concretes
  - Low water content
  - Low w/c
  - High paste
  - HRWRs

Settlement Cracking



Autogenous Shrinkage

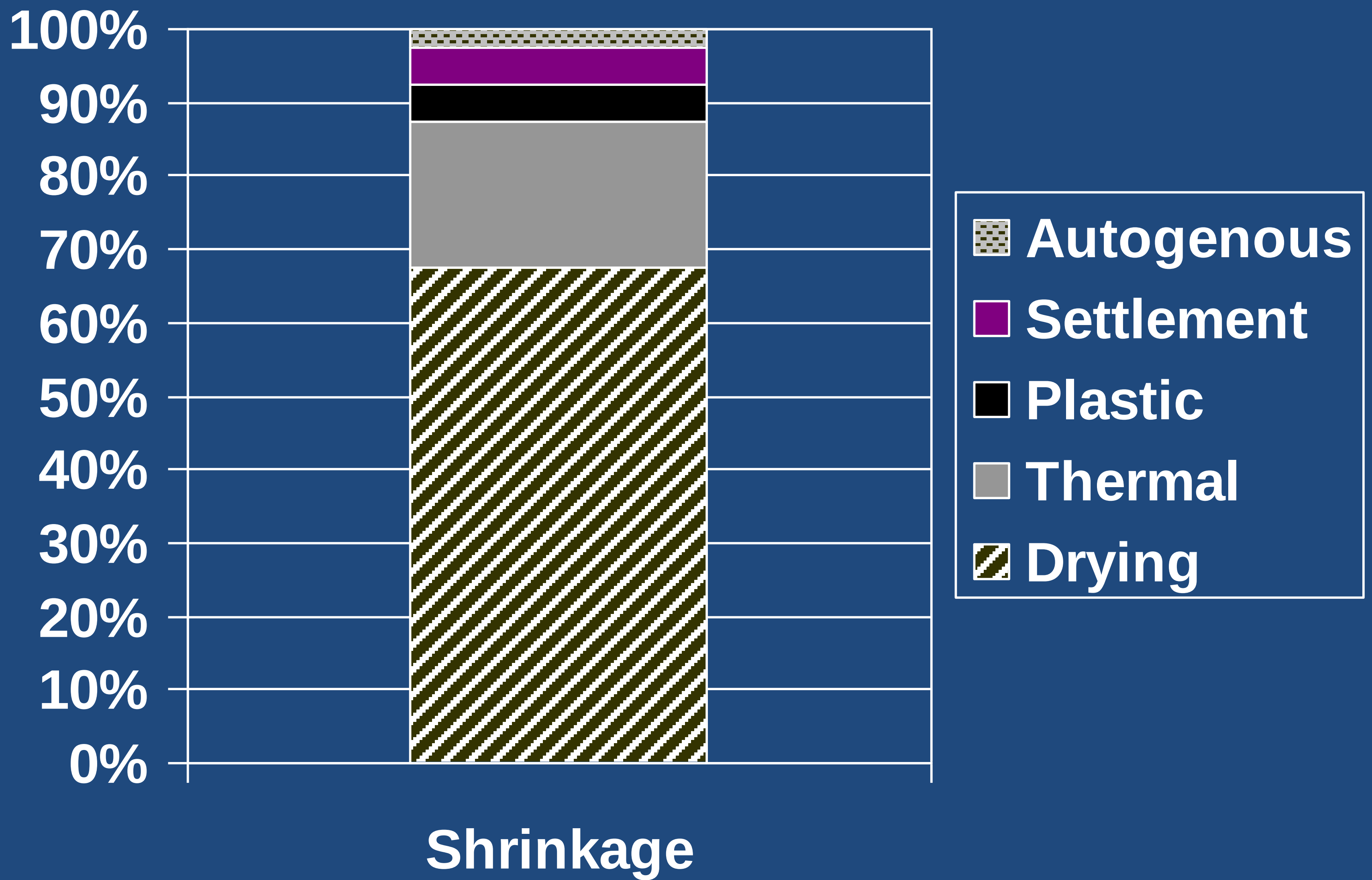
- First 12 to 24 hours
- Cement hydration process
- Usually simultaneous with thermal changes
- Concretes with higher autogenous shrinkage
  - High strength or "High performance" concrete
    - High cement content
    - Fine cements
    - Low w/c ratios
    - Fine mineral additives - silica fume

Thermal-induced Cracking

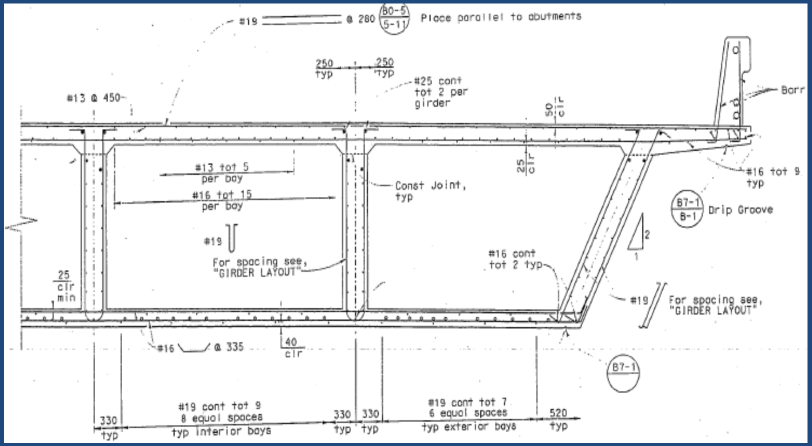
- First 12 to 24 hours, concrete temperatures change rapidly
- Heat of hydration causes concrete to expand, cooling causes shrinkage and cracking
- Diurnal and seasonal temperature changes

Drying Shrinkage

- Two phases
  - Loss of free water = moderate shrinkage
  - Loss of adsorbed water in capillary and pores = large shrinkage
- Humidity, wetting, mix affect drying shrinkage
- Differential, more shrinkage at surface (curling)


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Shrinkage
Autogenous
Settlement
Plastic
Thermal
Drying

Restraint Conditions



- External
  - End connections
  - Beams and webs
  - Friction
  - Composite connections
- Internal
  - Reinforcing steel
  - Section shape and profile

Research Approach

- Literature review (NCHRP, U of Kansas, others)
- Review of other DOTs
- Review of Caltrans practices
- Field and laboratory work
- Analytical studies (Equations/FEA/Lattice)
- Validation of potential solutions
- Recommendations

WJE Expertise and Team

- WJE
- Twining
  - Concrete materials testing
- UC Davis
  - Professor John Bolander, lattice modeling

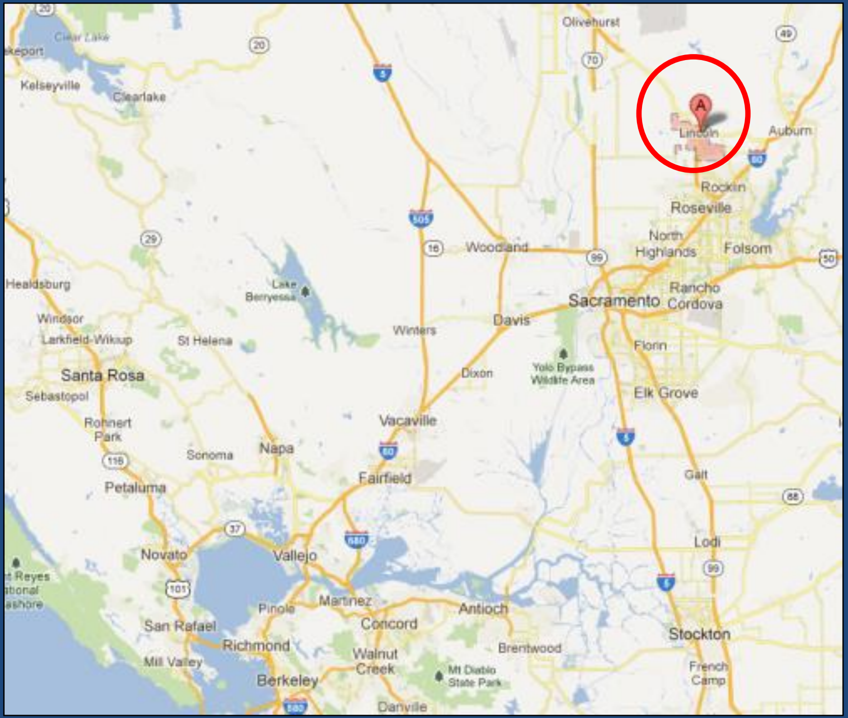
- <u>Review Panel</u>
  - Gary Janco of C.C. Myers
  - Prof. John Bolander, UC Davis
  - Boris Stein, Twining, Inc.
  - Mohammed Fatemi, Alta Vista Solutions
  - Prof. David Darwin, Kansas University
  - Prof. David Lange, University of Illinois

Special thanks to Madhwesh Raghavendrachar and Anthony Gugino (Caltrans)

Field Work

Case Studies

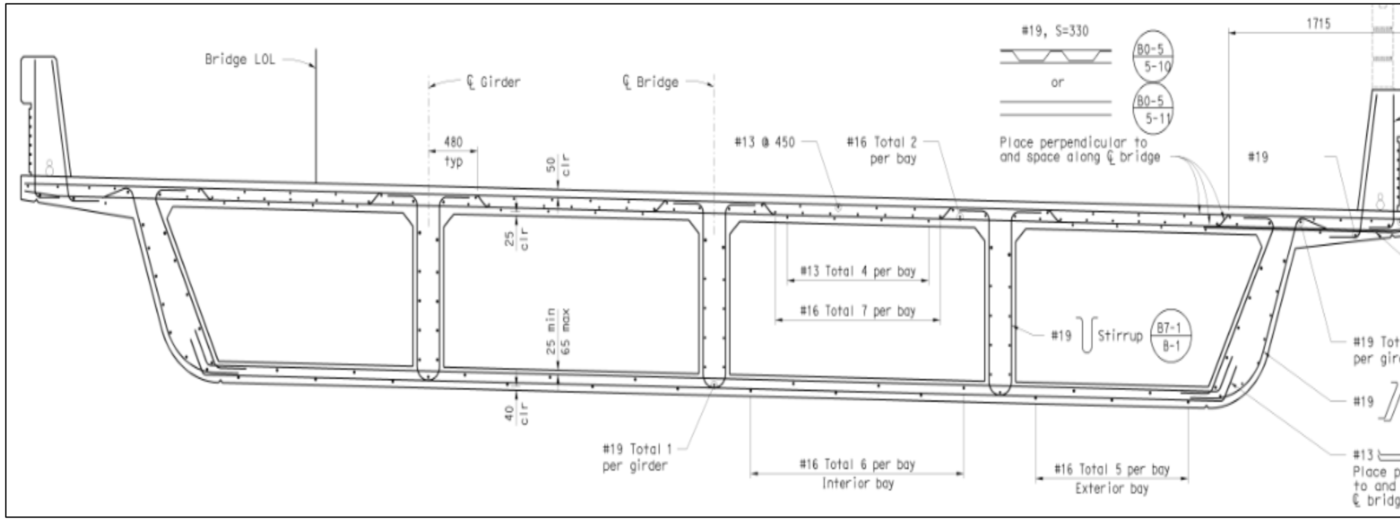
- Bridge in Lincoln, CA
  - Sacramento Area



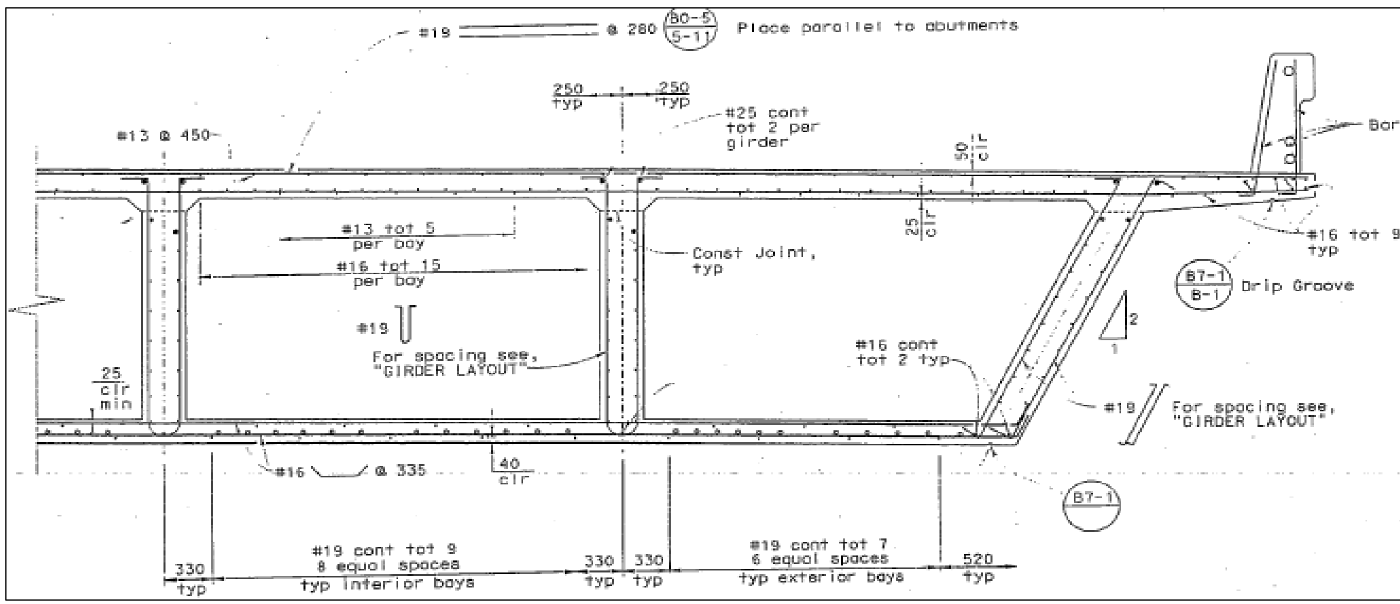
- Bridge in Santee, CA
  - San Diego Area

Case Studies

- Lincoln, CA

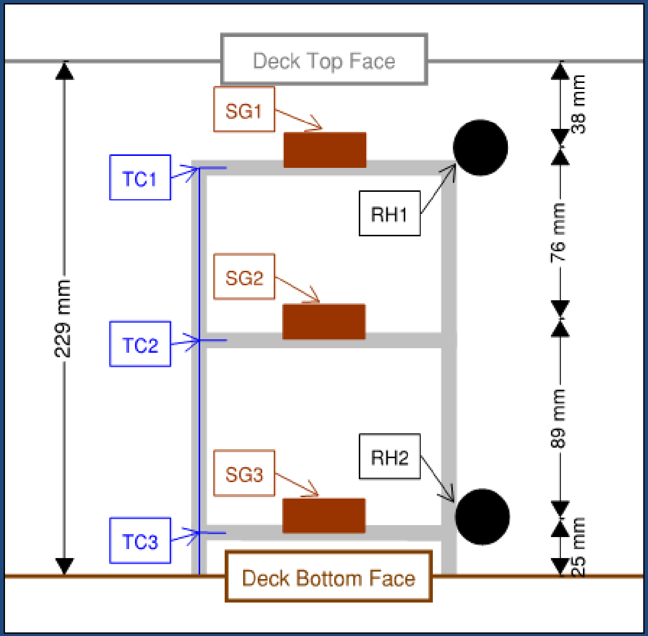


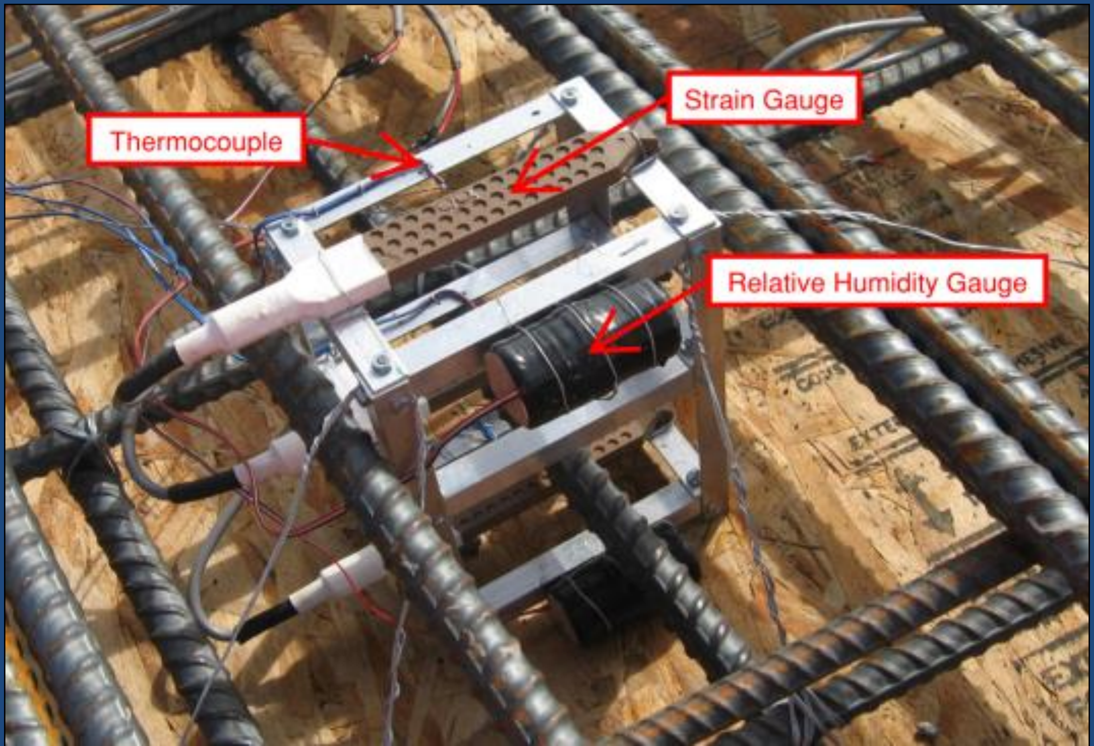
- Santee, CA



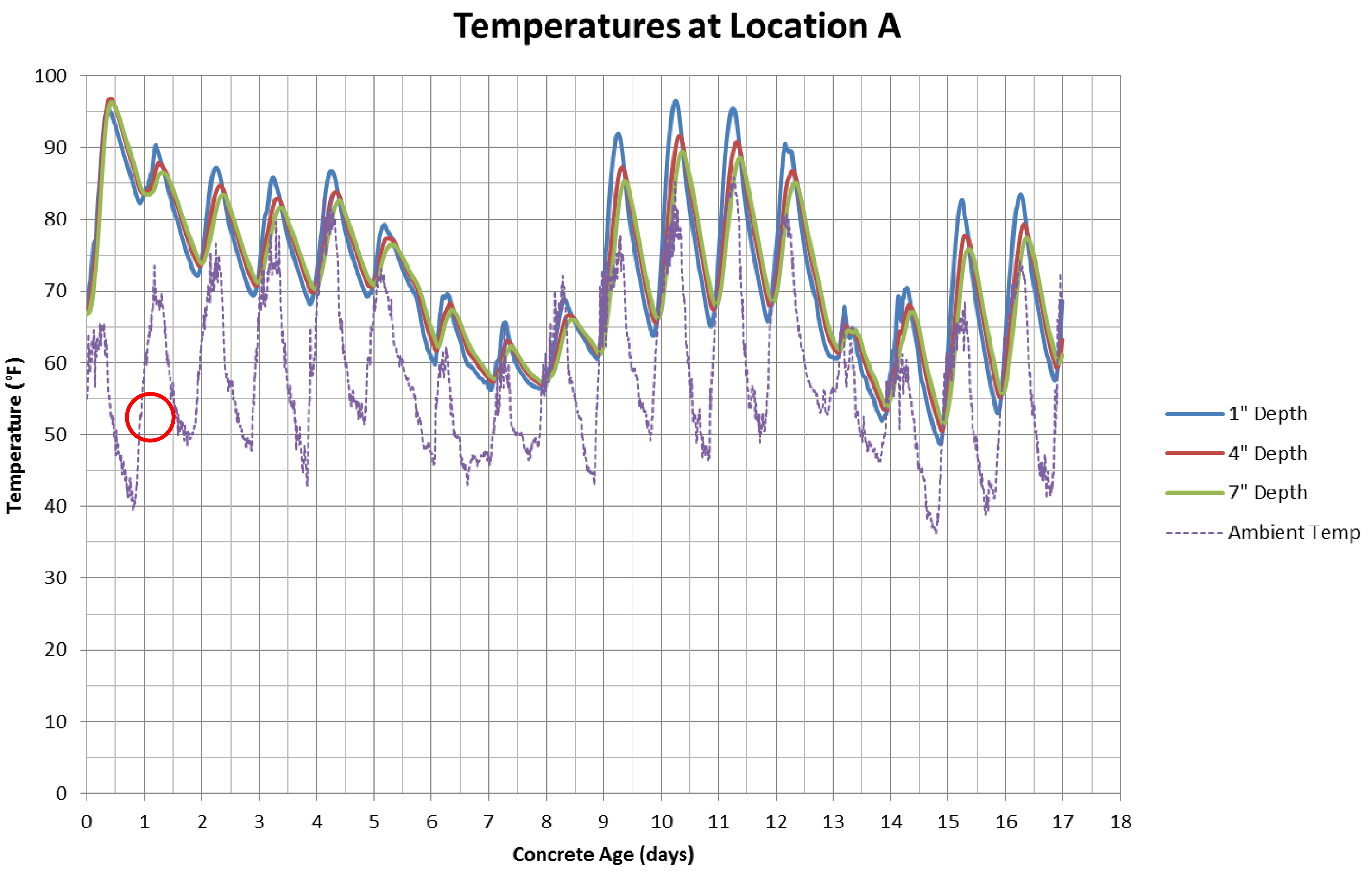
Instrumentation of Bridge Decks

- Data Acquisition
  - Instruments
    - Strain
    - Temperature
    - Relative humidity
    - Wind

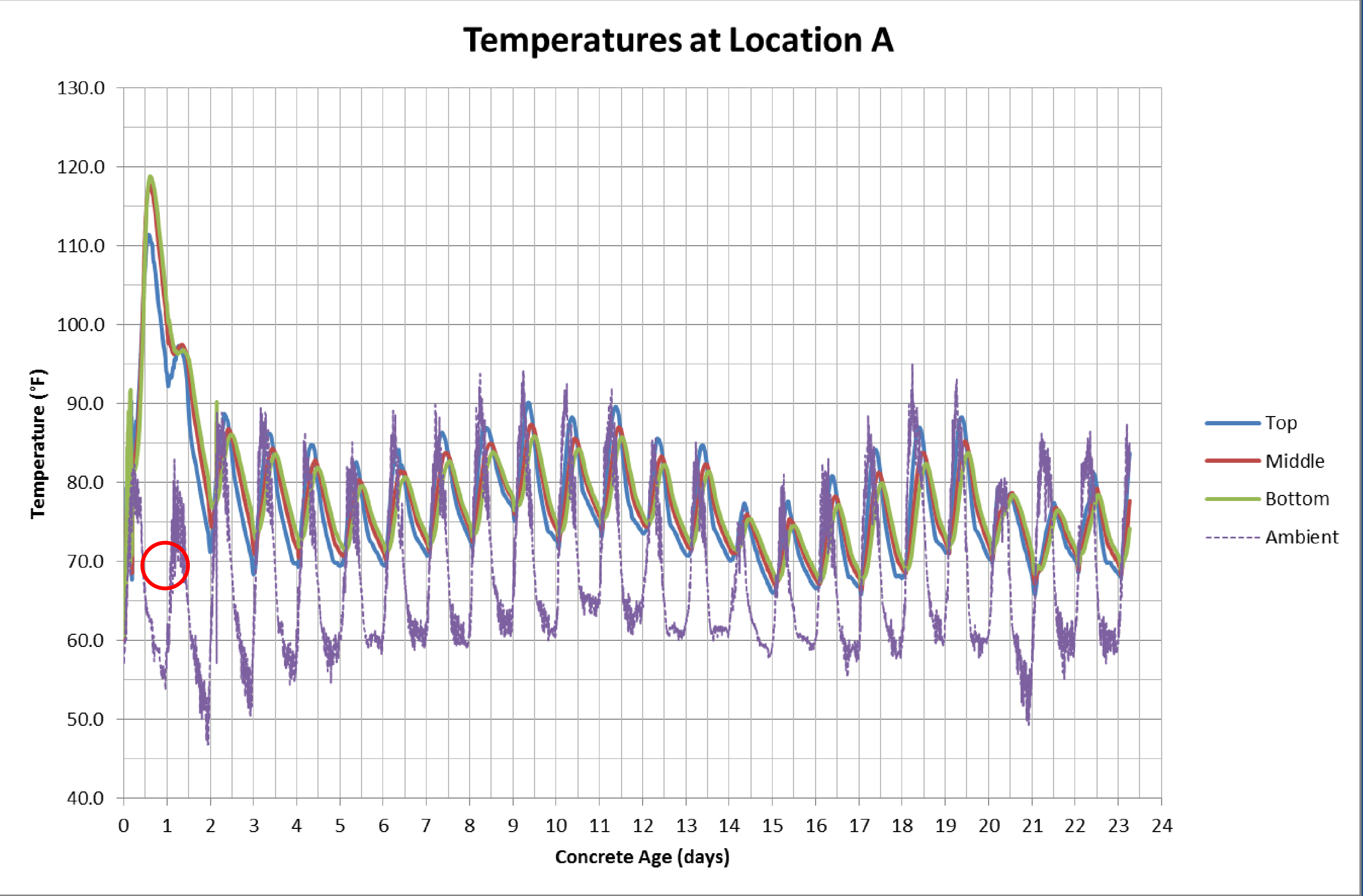




Temperature, Lincoln Bridge



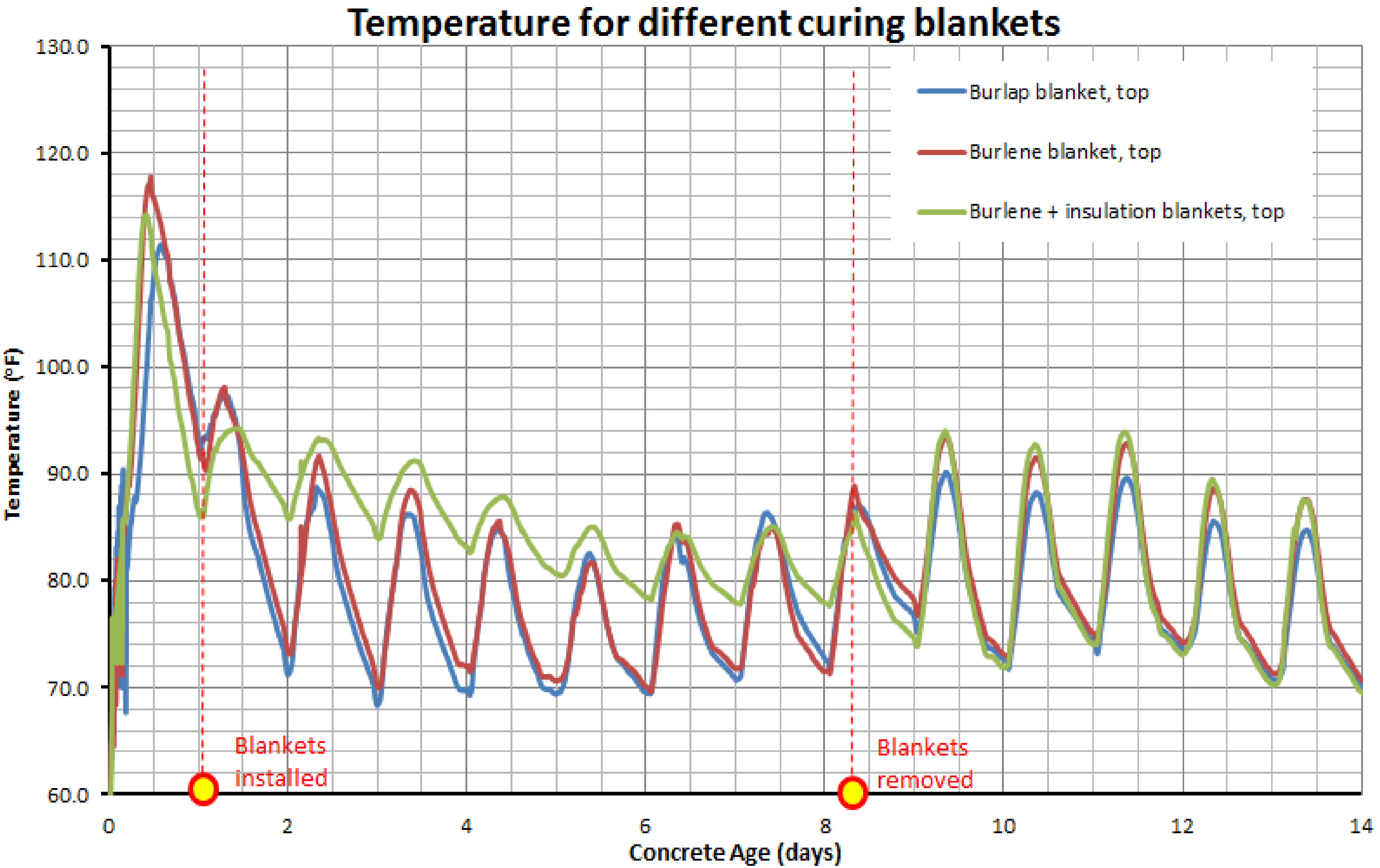
Temperature, Santee Bridge



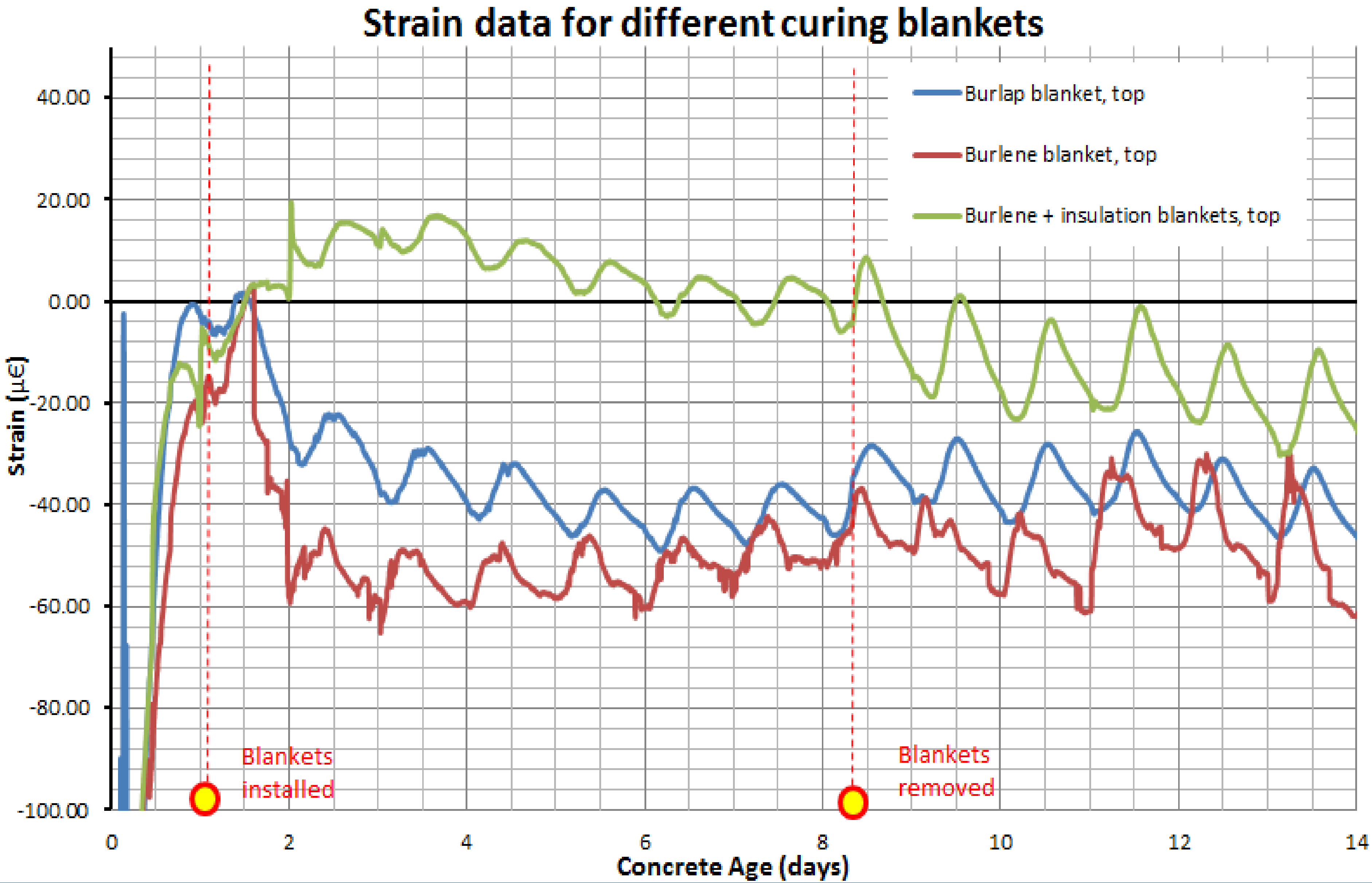
Effect of Curing Blankets

- Burlap
- Burlene
- Burlene+ insulation blankets

Curing Techniques

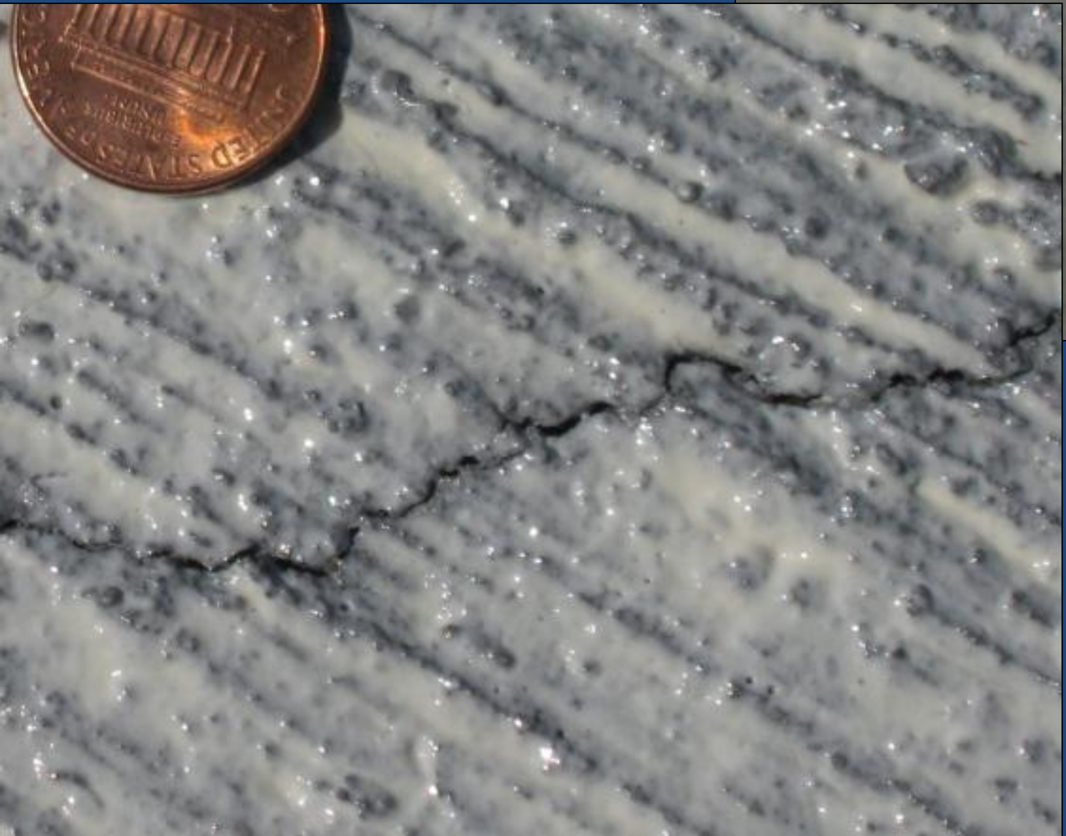


Curing Techniques



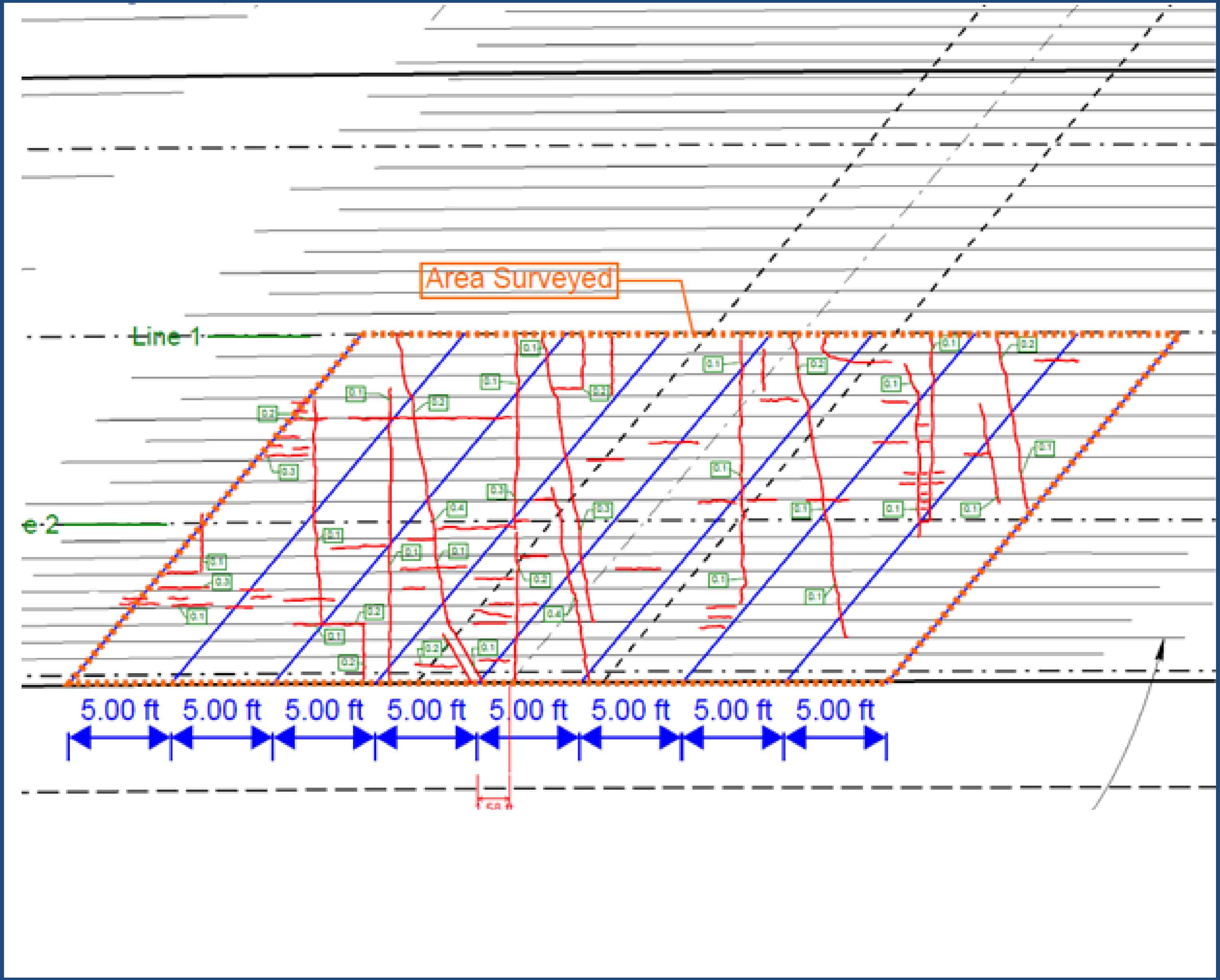
Curing Practices

- CC 2 hrs. after placing
- WC 20 hrs. after placing



Cracks 3-4 hrs. after placing

Crack Map 16 weeks after placing



Findings from the Field

- Current curing practices do not prevent plastic shrinkage cracking
- Thermal blankets applied after peak temperature reduced strains in the deck and slowed down cooling
- Application of a second coat of curing compound after wet curing reduced peak diurnal temperatures

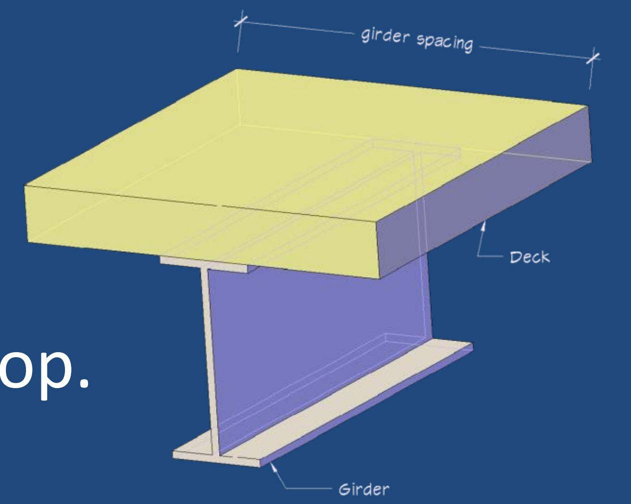
Analytical Studies

- Parametric studies
  - Linear elastic equations
  - 4CTemp&Stress
- Lattice modeling
  - Nonlinear
  - Explicit modeling of concrete prop.

$$\varepsilon_z = \frac{1}{E}[\sigma_z - \mu(\sigma_x + \sigma_y)] + \alpha T$$

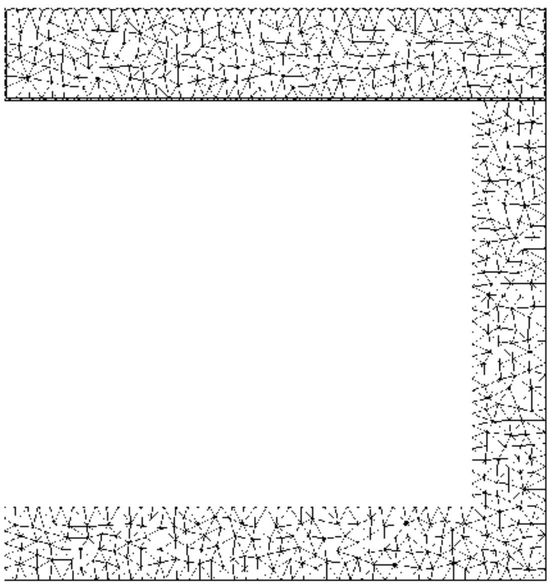
$$\varepsilon_y = \frac{1}{E}[\sigma_y - \mu(\sigma_x + \sigma_z)] + \alpha T$$

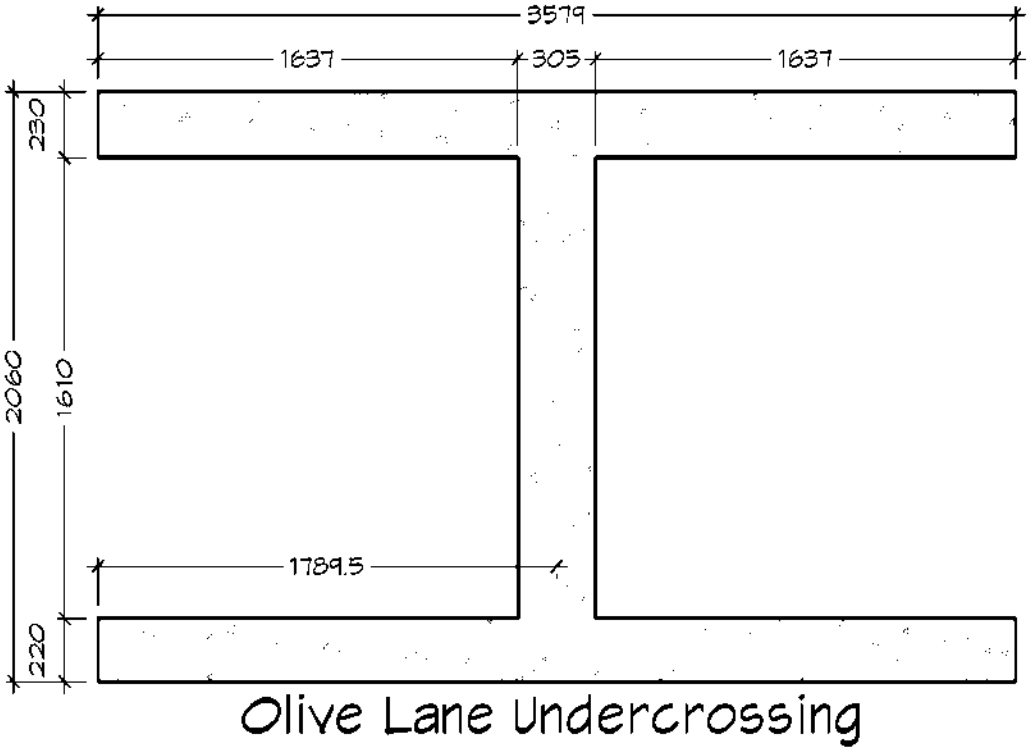
$$\varepsilon_x = \frac{1}{\varepsilon}[\sigma_x - \mu(\sigma_y + \sigma_z)] + \alpha T$$



Parametric Studies

4CTemp&Stress



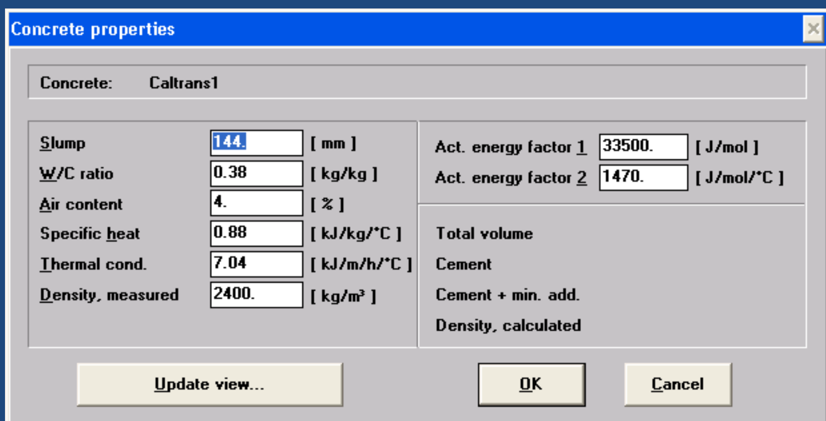


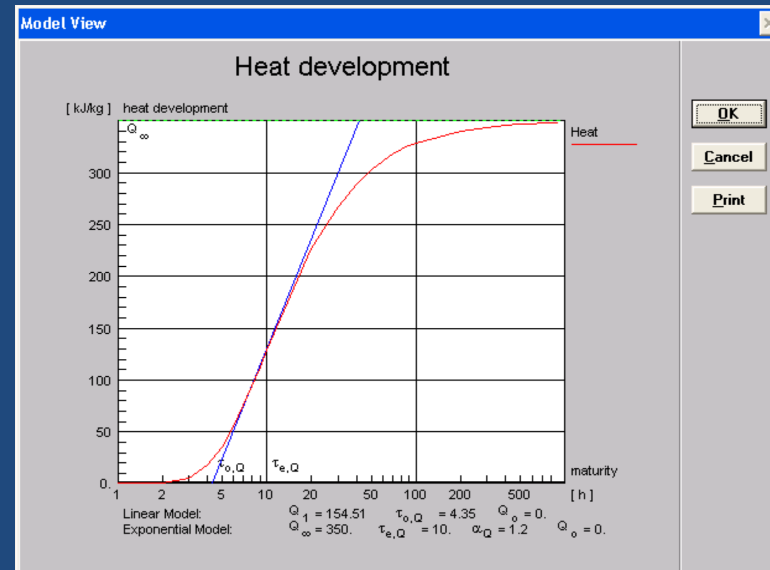
Parametric Studies

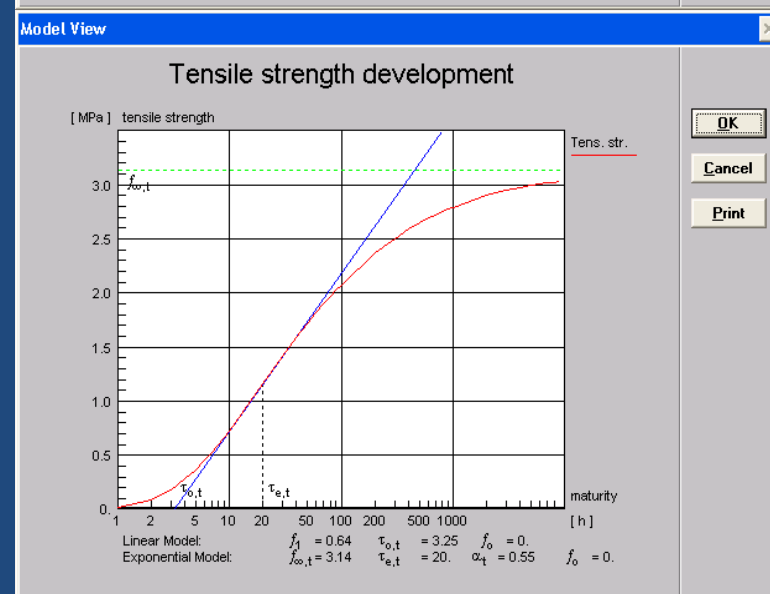
4CTemp&Stress

Two mixes:

- 675# cement
- 550# cement







Parametric Studies

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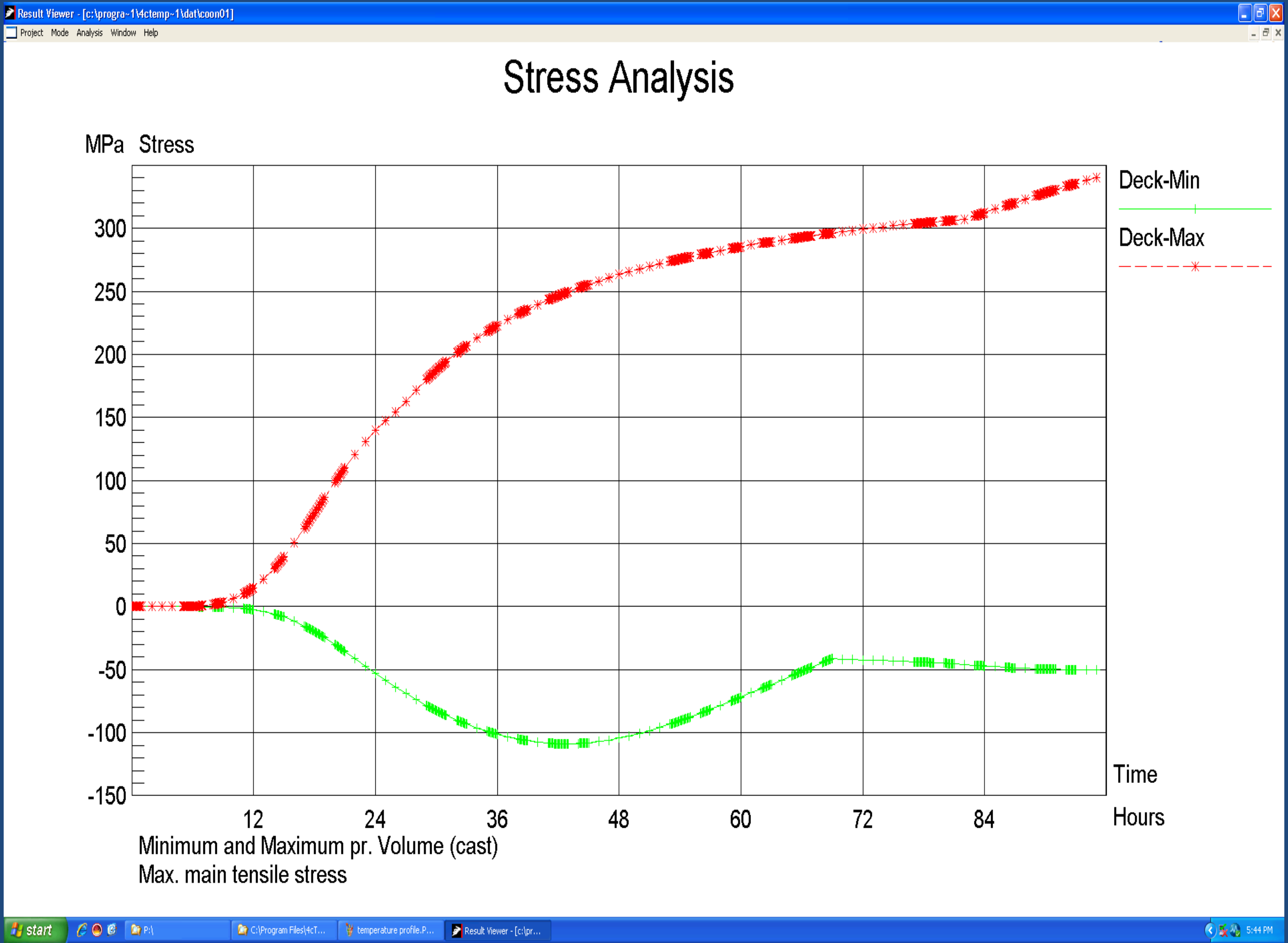
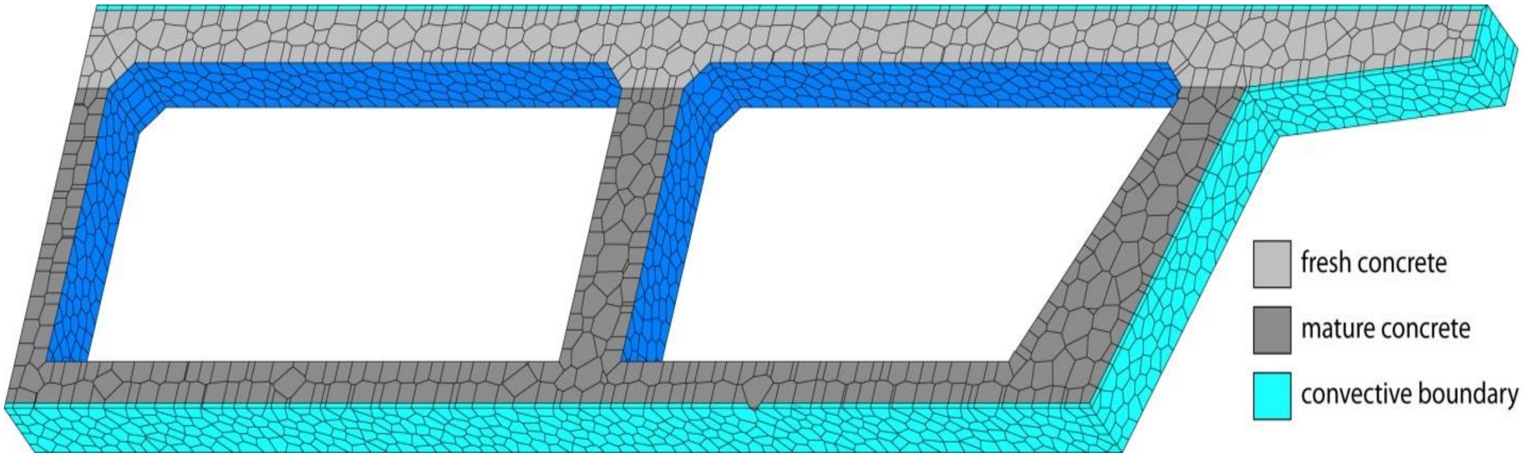
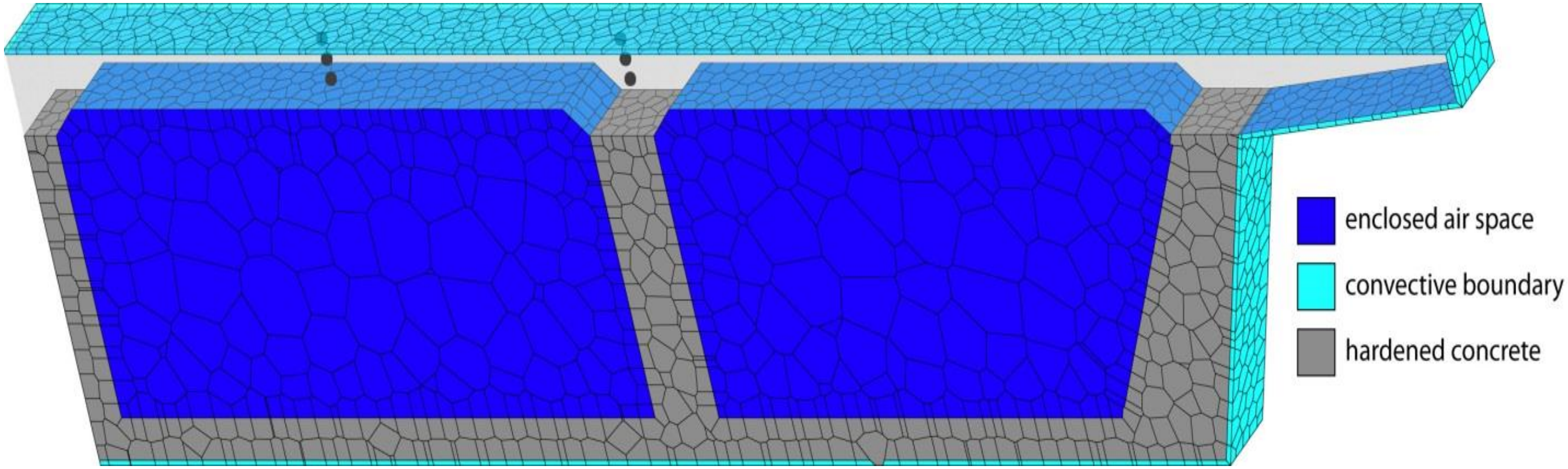


Lattice Modeling





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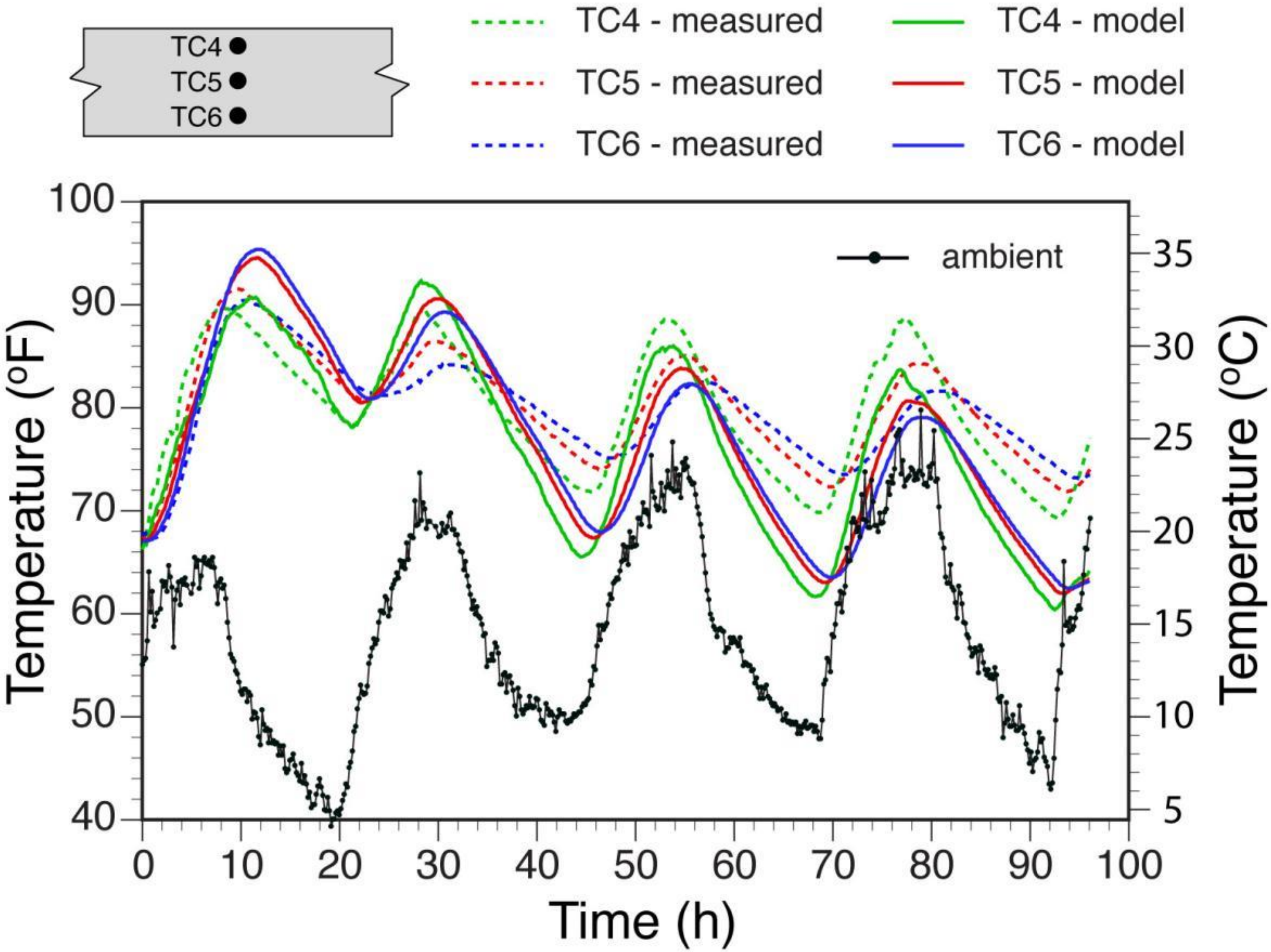
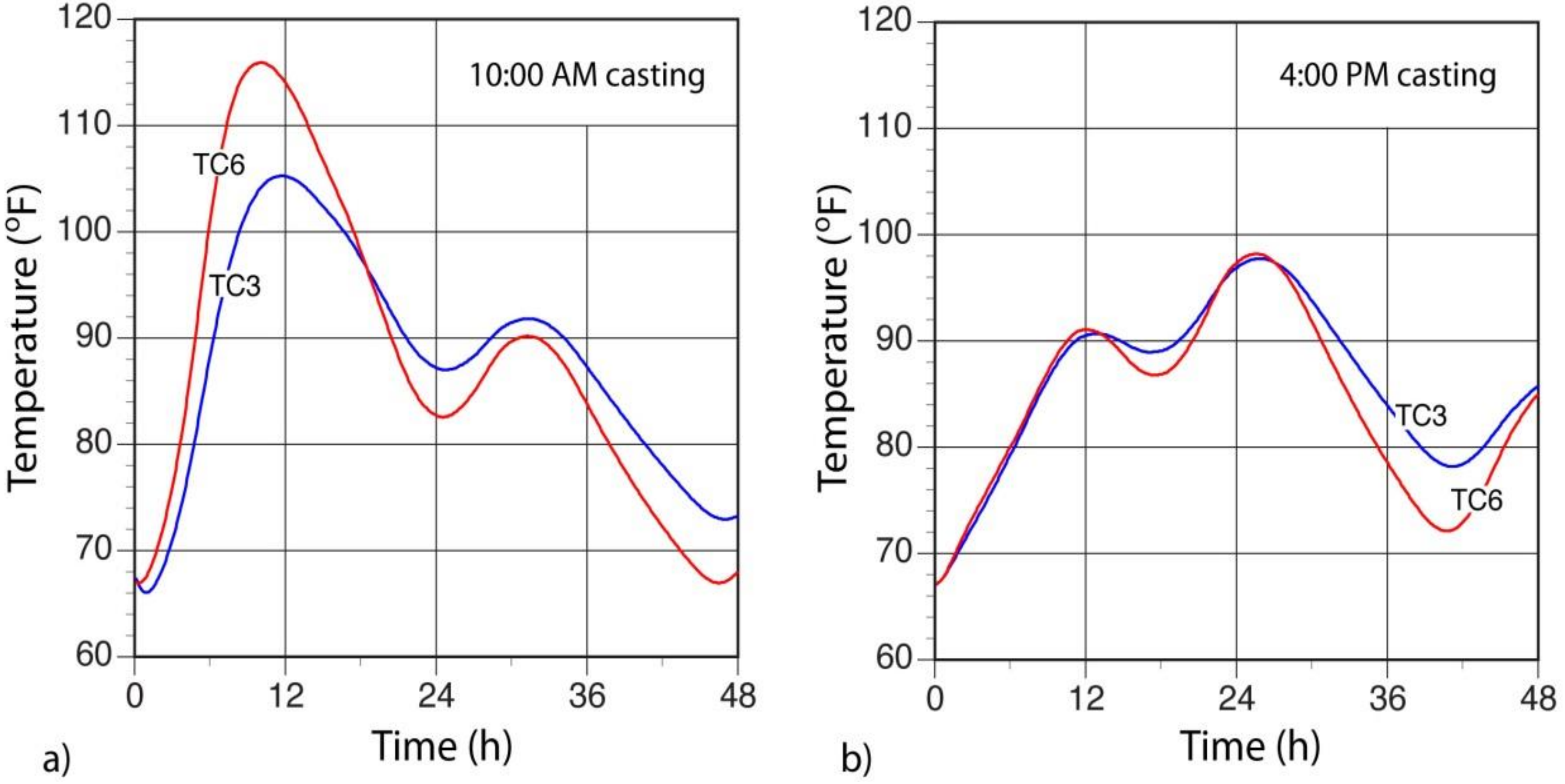


Lattice Modeling



Parameter & Lattice Findings

- Most benefit: reduce cement content
- Cast cooler concrete beneficial
  - Limit plastic concrete temperature to 75°F (24°C) at the time of placement
- Afternoon pours better than morning pours
- Larger webs/girders cause higher stresses
- Box girder decks cool slowly

Recommendations

Cementitious and Paste Content

- Eliminate minimum cementitious content requirement
- Maximum cementitious content of 600 pcy
- Maximum paste content of 27 percent
- Specify air entrainment of 6.0 to 8.0 percent regardless of exposure conditions

Recommendations

Strength and Mix Design

- Min. comp. strength: 3,600 psi (25 MPa) at 56 days
- Max. comp. strength: 4,500 psi (31 MPa) at 7 or 14 days
- Optimize aggregate gradation (KU Mix)
- Keep max. slump less than 4 in. (Kelly 2.5)
- Reduce maximum shrinkage requirement
  - (0.045% to 0.035% @ 28 d)
- Consider SRA's

Recommendations

Fly Ash and SCM's

- Avoid silica fume
- 21-day wet curing for blended cement concrete or fly ash containing concrete
- Allow ultra-fine fly ash or other SCM's only after testing shows no significant increase in shrinkage or cracking

Recommendations

Curing Methods

- Immediate misting and wet curing
  - Adequate equipment for wet curing
- Wet cure for 14 days
- Insulate deck
- Apply white curing compound after wet curing
- Cast in afternoon/evenings
- Hold a pre-job conference

Closure

- Early-age cracking results from complex interactions
- Recommendations will reduce early-age cracking
- Caltrans is developing a pilot program

- Thanks to Caltrans and industry participants

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