Bridge Deck Cracking
Types of Cracking

- Transverse
- Longitudinal
- Map
Transverse Cracking

- Appear before or shortly after opening
  - Typically less than 28 days
- Full depth
- Through plane of reinforcement
- Spaced 3 to 10 ft apart
- Concrete and steel superstructures
Transverse Cracking
Stay-in-place Forms
Wood Forming
Impact

- Delamination in Deck
- Corrosion of Reinforcement
- Full Depth Transverse Crack
Longitudinal Cracking
Construction Detail

7 7/8"

W36x150
Map Cracking

Typically observed in Overlays
General Experience

• Monolithic Concrete Structures
  – Least cracking
• Steel Superstructures
  – Most cracking
  – Restraint
    • Composite action
    • Stay-in-place steel forms
Deck Instrumentation
Temperature

Date (2000)

Temperature (°F)

Deck Temperature

Ambient Temperature
Longitudinal Reinforcing Strain

Microstrains

Date (2000)

-500

0

500

1000

1500

2000

2500

3000

8/15 8/20 8/25 8/30 9/4

Traffic

(C)

(T)
Stress Transfer

$\frac{7}{8}''$ #4 Top & #5 Bottom
Long. Bars @ 11 13/16''

$f_c' = 5,600 \text{ psi}$
@ 19 days

$f_{cr} = 6\sqrt{f_c'}$

$T_c = T_s$

$(450 \text{ psi})(12\text{ in.} \times 7\frac{7}{8}\text{ in.}) = (0.52\text{ in.}^2) f_s$

$f_s = 81,800 \text{ psi}$
Field Instrumentation Findings

- Transverse cracking at 19 days
- Longitudinal reinforcement yielded
- Cracking not influenced by live loads
Field Investigations

• 4 bridges
  – I-65 (Standard Design)
  – SR 18 (Empirical Designs)
  – Thayer Road Bridge (FRP)
  – SR 23 (HPC & Purdue Empirical)

• Instrumentation
  – Strain Gauges
  – Thermocouples

• Crack Mapping
Field Study Findings

• Field Investigation
  – Low shrinkage concrete decreases cracking
  – Reinforcement affects cracking
  – Thermal effects contribute to cracking
  – Crack Growth
    • Maximum cracks 5x initial
  – Reinforcement may yield
Restrained Shrinkage

• Eliminate Restraint
  – Composite action
  – Pan forms

• Eliminate Shrinkage
  – Concrete shrinks

• Eliminate Cracking
  – Minimize cracking
Laboratory Composite Models

As Built

Free Shrinkage
Shrinkage Investigation

Direction Of Shrinkage Measurement

4’-4”

7 7/8”

2’-9 1/2”
Specimen Variables

- Wood Forms
  - Unsealed
  - Sealed
- SIP Forms
  - Transverse
  - Longitudinal
- Reinforcement
- Thickness
Effect of Sealing

Top of Deck

Sealed

Unsealed

Micro Strains

300 0 -300

7-7/8”
Deck Pan Stiffness

Longitudinal Orientation

Top

Transverse Orientation

No Pan (Sealed)

Deck Pan (Sealed)

Micro Strains

9 7/8”
Concrete shrinkage & curing
Low Shrinkage Concrete

- Reduced cement and water content
- Increased sand, addition of fly ash

![Graph showing the compressive strength of low shrinkage concrete over time.]
Shrinkage Behavior

- Wet Cure
- Drying Shrinkage
- Thermal expansion and shrinkage
Effect of Concrete Mix

- Long term effects
  - Low shrinkage mix: decreased total shrinkage
Reinforcement Stress at Time of Cracking

\[ f_t = 6\sqrt{f_c} \]

\[ F_c = 6\sqrt{f_c A_c} \]

\[ T = F_c \]

\[ A_c \left( 6\sqrt{f_c} \right) = A_s f_s \]

\[ \rho_g = \frac{6\sqrt{f_c}}{f_y} \]
Maximum Crack Width

9” Spacing

Steel Stress (ksi)

Crack Width (mils)

1.3 Factor
Reinforcement Layout

18” Spacing, #4 bar
Minimum 0.27%  $\rho_g$  Maximum 1.25%

4” Spacing, #4 bar
Specimen Construction
Control Cracking

Design

Construction

Materials
Recommendations

• Curing is Essential
  – Minimum 7 day wet cure
• Minimize drying shrinkage
  – Mix design
  – Minimize concrete strength
• Alternative forming system
  – Flat forms
  – Remove forms
Recommendations

• Additional reinforcement required
  – Above Shrinkage and Temperature

\[
A_s = \frac{6\sqrt{f_c'}}{f_y} A_g
\]

– Max spacing 9 in. for Epoxy Coated Reinforcement