Best Practices in Bridge Deck Construction

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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

Corrosion of Reinforcement

Delamination in Deck

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
Field Instrumentation
I65 over SR25
Deck Instrumentation
Longitudinal Reinforcing Strain

Microstrains

Date (2000)

Traffic

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

$7 7/8''$  
$12''$  
$\#4$ 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

- 4’-4"
- 2’-9 1/2"
- 7 7/8"

Direction Of Shrinkage Measurement
Specimen Variables

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

Top of Deck

Micro Strains

Sealed

Unsealed

7-7/8”
Deck Pan Stiffness

Longitudinal Orientation
Top
Transverse Orientation

Micro Strains
300 0 -300

Micro Strains
300 0 -300

No Pan (Sealed)

Deck Pan (Sealed)

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

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

![Diagram showing compressive strength over time for Low Shrinkage and Class C concrete](chart.png)
Shrinkage Behavior

\[
\text{Strain (\(\mu\varepsilon\))}
\]

- Wet Cure
- Drying Shrinkage
- Thermal expansion and shrinkage

\[
\text{Time (days)}
\]
Effect of Concrete Mix

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

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

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

\[ T = A_{sf} \]

\[ A_c (6\sqrt{f_c}) = A_{sf} f_s \]

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

Steel Stress (ksi) vs. Crack Width (mils) for 9" Spacing

- Black: 6 mils
- 6 mils: 18 mils
- 12 mils: 1.3 Factor

0 5 10 15 20 25 30
0 10 20 30 40 50 60 70
Steel Stress (ksi)
Crack Width (mils)

1.3 Factor
Reinforcement Layout

18” Spacing, #4 bar
Minimum 0.27%

4” Spacing, #4 bar
$\rho_g$ (Minimum 1.25%)
Specimen Construction
Strain - # 4 Bars

Strain (µ)

Time (Days)

S1 (ρ=0.27%, s=18’’)
S4 (ρ=0.42%, s=12’’)
S6 (ρ=0.63%, s=8’’)
S2 (ρ=1.25%, s=4’’)
Concrete Shrinkage
Control Cracking

- Design
- Construction
- Materials
Recommends 

- 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