“Creating Long Life Pavement Solutions”

*Design & Performance Of CRCP*

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US DOT, FHWA   California DOT   ACPA/CRSI
Design & Performance of CRCP
---Outline---

- Design criteria for CRCP
- Major elements of CRCP design
- Brief CRCP history
- CRCP design procedures
  - AASTHO 1993 CRCP
  - AASHTO 2007 CRCP (MEPDG or DARWin-ME)
- State practice, modern designs, European designs, composite designs
- Recommended long life CRCP design
CRCP Design Criteria

- **Crack spacing** is ideally between 3 and 6-ft.
- **Crack width** is recommended to be very narrow, typically in the order of 0.020-in. as measured at the top of the slab. Note: 0.040-in as recommended by some is way too wide!
Crack Spacing & Width
(Vandalia, IL 1947-1967)

![Graph showing crack spacing and width as functions of percent reinforcement.](image-url)
CRCP Design Criteria

- Structural edge punchout from PCC fatigue damage at top of slab due to axle load repetitions, upward curling, & loss of support. Fatigue damage is correlated to edge punchouts in the field.
CRCP Design Criteria

- Smoothness (serviceability index and IRI). Long term performance studies have shown that well designed & constructed CRCP built smooth initially will remain smooth over the design life & beyond.

  - Long term smoothness depends mostly on initial constructed smoothness.
  - Historical LTPP IRI data plotted over 20 years shows many CRCP with nearly “flat” IRI performance curve.
Initial Smoothness, CA 1949
(CRCP & JPCP Profile)
Long Term Smoothness CRCP
(LTPP GPS-5)
Major CRCP Design & Construction Elements

- Longitudinal steel design
- Slab thickness design
- Support: Base & subbase design
- Tied concrete shoulders, widened slab design
- Concrete properties design
- Construction weather & quality
- Terminal anchors (not this presentation)
Evolution of CRCP Design Procedure

  - Performance observed for 20-years, lasted >50 years.
- Became standard procedure in Illinois, Texas and other States in 1960’s.
- CRCP designed based on AASHO Road Test results for Jointed Concrete Pavements in 1960s and 1970s.
  - Lower J-factor which decreased thickness 1-2-in.
- Reinforcement content based on IL, CA, TX, and other experimental results.
- AASHTO Interim Guide included CRCP design 1971 as alternate with lower J Factor and reinforcement design.
Evolution of CRCP Design Procedure, Cont.

- Typical CRCP designs in 1960’s & 1970’s
  - 8-in slab
  - 0.55 to 0.67 % steel
  - All types of bases: aggregate, cement, asphalt
  - Shoulder: Asphalt

- Some CRCP failures observed in 1970’s from construction and design problems
  - Major repairs required to maintain inservice
  - Many States stopped CRCP construction
  - IL, TX, OR, SD, and others learned how to design and build & continued to build
Evolution of CRCP Design Procedure, Cont.

- Illinois DOT conducted research to develop better design and repair procedures (Schwartz, Taylor, Barenberg, Darter, Roesler, many others in 1960’s-today)
  - Construction problems identified and corrected (e.g., steel placement, base type & erosion, steel laps, …)
  - Repair procedures and performance studies
  - Reinforcement content and depth of placement
  - Base type, anchor lugs

- Texas DOT conducted extensive research also in 1960-today (McCullough, Won, Zollinger, others).
Evolution of CRCP Design Procedure, Cont.

- Concurrent studies by FHWA, TX, IL, and other States
  - Demonstrated deficiencies in design process
  - Large crack-widths being permitted in design (0.04 in design width was disaster)
  - Inadequate reinforcement content (disaster)
  - Erosion of base course, loss of support (dis.)
  - Erroneous extrapolation from JCP to CRCP
  - Tied PCC shoulders benefits
1986/93 AASHTO Pavement Design Guide

- Empirical methodology based on AASHO Road Test in the late 1950’s
  - Only JPCP & JRCP sections
  - 1961 Nothing on CRCP
  - 1972 Adds crude extension to CRCP (empirical reduction thick, crack width, steel stress)
  - 1986 & 1993 Design Reliability, J-factor, etc. added
  - 1996 National consensus on need for improved design
  - 1998-2007 NCHRP 1-37A (new CRCP mechanistic based design), Not based on jointed design.
Evolution of AASHTO CRCP Design Procedure, Cont.

- As result of 1986/93 AASHTO changes & increased traffic, CRCP design changed in late 1980’s
  - Slabs became thicker, same as JPCP: 10-in to 14-in (17-in TX)
  - Increased reinforcement: 0.6 to 0.7/0.8 percent
  - Better base support: typically hot-mixed asphalt, sometimes as only base layer and sometimes placed between CRCP & CTB to stop erosion.
  - Tied PCC shoulders, some widened slabs

Minimal problems since then (mostly construction errors or PCC durability problems) & but high cost!
Evolution of AASHTO CRCP Design Procedure, Cont.

- AASHTO 1986/93 Revision –
  - Improvements for steel reinforcement design.
  - The allowable crack width should not exceed 1 mm (0.040in), as recommended by AASHTO. **However, research suggests a value between 0.50 and 0.625 mm (0.020 and 0.025 in) is required.** The smaller the crack width, the better chance there is for high crack load transfer and low steel stresses.
  - Slab thickness became the same for CRCP and Jointed Plain Concrete Pavements (JPCP)
AASHTO 2007
MEPDG (DARWin-ME)
CRCP Design

- New State-of-the-Art CRCP design procedure
- Development of mechanistic based models:
  - Crack spacing—long term mean
  - Crack width—varies monthly & increases w/time
  - Crack load transfer efficiency—monthly
  - Punchout—structural repeated load edge failure
- Development of empirical IRI model
  - \( IRI = f(\text{Initial IRI, future distress, site conditions}) \)
AASTHO 2007 DARWin-ME

CRCP

- Base Course (agg., asph, cem)
- Subbase (unbound, stabilized)
- Compacted Subgrade
- Natural Subgrade
- Bedrock
Materials

Structure

Climate

Axle load (lb)

Traffic

DG Inputs

DG Process

DG Outputs

Mechanistic
Response

Damage Accumulation

Distress Prediction and Reliability

Field Distress
Pennsylvania LTPP Section 42-5020

Cumulative Truck Volume per Lane

Average Crack Width

Average Crack LTE

Punchout per mile

Pavement age, years

Slab thickness: 9.3 inch
% Steel: 0.6
Base Type: GB
Avg. crack spacing: 55 inch
Climatic zone: WF
AADTT (base year): 1,100
Avg. ESAL/truck: 1.0
Truck Growth: 6.50%
Punchout: Structural Distress
CRCP

Medium & High Severity Levels Included
Top-Down Punchout Cracking Mechanism

Traffic

Critical Stress Location Top of Slab

Pavement Edge

Transverse Crack
CRCP Response Model

with Loss of Support, Build-in Curling, and Temperature Gradient

Top Surface Stress (psi)

208.4
193.7
171.6
149.5
127.5
105.4
83.3
61.3
39.2
17.1
-5.0
-27.0
-49.1
-71.2
-78.5

Single Axle Wheels Location
Max Top Tensile Stress Location
CRCP Stress Distribution for Different Transverse Crack LTE

LTE = 95%

LTE = 20%

Direction of traffic

150

342
Key Design Factors Considered
AASHTO DARWin-ME

1. Slab thickness
2. Concrete: strength, CTE, ultimate shrinkage
3. Reinforcement: % steel, depth in slab
4. Slab supporting layers: friction & loss of support
5. Full spectrum of axle type & loading & traffic wander
6. Temperature & moisture differentials through the slab thickness
7. Transverse crack spacing as a function of pavement design parameters & friction with base
8. Changes in transverse crack width and crack load transfer over service life
9. Development of edge punchouts during service life
NATIONAL CALIBRATION OF
THE 2007 AASHTO
DARWIN-ME FOR CRCP
Nationwide Distribution of CRCP Calibration Sections

* IL sections
- 7 - LTPP
- 6 - Vandalia
- 8 - I-80
- 3 - I-94
- 3 – Unbonded OL

# SC sections
- 3 - LTPP
- 12 - I-77
## IL Vandalia Sections

### Crack Spacing and Crack Width, 20-years

<table>
<thead>
<tr>
<th>Slab thickness</th>
<th>Percent Steel</th>
<th>Crack Spacing, inch</th>
<th>Crack Width, mils</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Measured</td>
<td>Predicted</td>
</tr>
<tr>
<td>7</td>
<td>0.5</td>
<td>78</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>68</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>60</td>
<td>54</td>
</tr>
<tr>
<td>8</td>
<td>0.5</td>
<td>90</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>72</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>60</td>
<td>56</td>
</tr>
<tr>
<td>Mean</td>
<td>-</td>
<td>84</td>
<td>84</td>
</tr>
</tbody>
</table>
Punchout Prediction

(Chicago I-80 WB M.P. 137.65)
Punchout Prediction Example – I-77 521 Outer Lane

- Predicted PO/mile 521 NB Outer lane
- Measured PO/mile 521 NB Outer lane
- Predicted PO/mile 521 SB Outer lane
- Measured PO/mile 521 SB Outer lane
Punchout Prediction Example – LTPP 48-5310

- Measured punchout
- Predicted punchout

Pavement age, years

Punchout per mile
Punchout Prediction Example – LTPP 9-0501

- Measured punchout
- Predicted punchout

Pavement age, years vs. Pavement punchout per mile
IRI Prediction Example – LTPP 19_5046

Predicted IRI

Measured IRI
IRI Prediction for All CRCP Sections

- N=165
- $R^2=0.473$
- SEE=7.5
SENSITIVITY OF THE 2007 AASHTO MEPDG (DARWIN-ME) FOR CRCP
**Effect Steel Depth – I-70, IL**  
*(8-inch, 20 years field data)*

<table>
<thead>
<tr>
<th>Steel depth (inch)</th>
<th>Crack spacing (feet)</th>
<th>Crack width (inch)</th>
<th>Patching (sf/1000 ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.4</td>
<td>0.0187</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>3.8</td>
<td>0.0312</td>
<td>13</td>
</tr>
<tr>
<td>4 (mid-depth)</td>
<td>5.4</td>
<td>0.0327</td>
<td>31</td>
</tr>
</tbody>
</table>
## Effect of Steel Depth – I-70 IL
(8-inch slab 20 years)

<table>
<thead>
<tr>
<th>Steel depth (inch)</th>
<th>Crack spacing (inch)</th>
<th>Crack width (inch)</th>
<th>Punchout/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Field</td>
<td>M-E PDG</td>
<td>Field</td>
</tr>
<tr>
<td>2</td>
<td>29</td>
<td>36</td>
<td>0.019</td>
</tr>
<tr>
<td>3</td>
<td>46</td>
<td>49</td>
<td>0.031</td>
</tr>
<tr>
<td>4 (mid-depth)</td>
<td>65</td>
<td>66</td>
<td>0.033</td>
</tr>
</tbody>
</table>
Effect of Steel Depth
(I-77 9-in Sections South Carolina)
Effect of Steel Depth, 11-in

LTE, % vs Depth of steel, inch

AASHTO 2007
MEPDG
Effect of Steel Depth, 11-in CRCP

AASHTO 2007 MEPDG

Diagram showing the relationship between crack width and crack spacing with depth of steel.
CRCP Thickness & Steel %
Illinois Empirical Performance 2000

Illinois CRCP

 Failures/km

% Steel
- 0.5
- 0.6
- 0.7
- 0.8

Slab Thickness, cm
18 7-in
20 8-in
23 9-in
25 10-in
Slab Thickness Sensitivity for North Dakota LTPP Section 38-5002

LTPP Section: 38-5002
State: ND
Slab thickness: 8 inch
% Steel: 0.6
Base type: ATB
Climatic zone: DF
ADTT (base year): 480
Avg. ESAL/truck: 0.7
Truck Growth: 5.0%

Graph showing punchouts per mile versus age (years) for different slab thicknesses:
- 7-in slab
- 8-in slab (LTPP)
- 9-in slab
- 11-in slab
Impact of Reinforcement %
(20-years Vandalia Experiment, IL)

8-inch CRCP thickness

Measured crack spacing
Predicted crack spacing
Measured crack width
Predicted crack width
Effect of Steel Content, MEPDG

![Graph showing the effect of steel content on punchout per mile. The graph has a y-axis labeled 'Punchout per mile' ranging from 0 to 20 and an x-axis labeled 'Longitudinal steel content, percent' ranging from 0.5 to 0.9. The data points indicate a decreasing trend as the steel content increases.]
Longitudinal Steel % Sensitivity for Illinois LTPP section 17-5843

- **LTPP Section**: 17-5843
- **State**: IL
- **Slab thickness**: 10.4 inch
- **% Steel**: 0.68
- **Base type**: CTB
- **Climatic zone**: WF
- **ADTT (base year)**: 1,700
- **Avg. ESAL/truck**: 1.5
- **Compound Growth**: 3.6%

Graph showing punchouts per year versus age in years. The graph includes data points for 0.5%, 0.65%, 0.68%, and 0.8% steel.
PCC CTE Sensitivity for Mississippi LTPP Section 28-5006

<table>
<thead>
<tr>
<th>LTPP Section</th>
<th>28-5006</th>
</tr>
</thead>
<tbody>
<tr>
<td>State</td>
<td>MS</td>
</tr>
<tr>
<td>Slab thickness</td>
<td>8.2 inch</td>
</tr>
<tr>
<td>% Steel</td>
<td>0.59</td>
</tr>
<tr>
<td>Base type</td>
<td>CTB</td>
</tr>
<tr>
<td>Climatic zone</td>
<td>WNF</td>
</tr>
<tr>
<td>ADTT (base year)</td>
<td>500</td>
</tr>
<tr>
<td>Avg. ESAL/truck</td>
<td>1.1</td>
</tr>
<tr>
<td>Compound Growth</td>
<td>8.0%</td>
</tr>
</tbody>
</table>

CTE = $7 \times 10^{-6}$ °F$^{-1}$

CTE = $5.5 \times 10^{-6}$ °F$^{-1}$ (LTPP)

CTE = $4 \times 10^{-6}$ °F$^{-1}$
Design Thickness Comparison
CRCP Vs JPCP

Traffic:
100 million trucks

JPCP:
15-ft joint spacing
1.5” dia dowels
Tied PCC Shoulder IL Exp.

- Illinois CRCP performance data shows that in side by side comparison, tied concrete shoulders reduce punchouts significantly.
USA & EUROPEAN CRCP PRACTICE & CRCP DESIGN EXAMPLES
## CRCP State Practice Comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>Illinois</th>
<th>Oklahoma</th>
<th>Oregon</th>
<th>South Dakota</th>
<th>Texas</th>
<th>Virginia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Mod AASHTO</td>
<td>AASHTO</td>
<td>AASHTO</td>
<td>AASHTO</td>
<td>Mod AASHTO</td>
<td>AASTHO</td>
</tr>
<tr>
<td>Slab</td>
<td>9 – 14 in</td>
<td>9 - 12</td>
<td>8 - 12</td>
<td>8 - 11</td>
<td>8 - 15</td>
<td>10 - 11</td>
</tr>
<tr>
<td>% Steel</td>
<td>0.70</td>
<td>0.72</td>
<td>0.6-0.7</td>
<td>0.70</td>
<td>0.71-0.78</td>
<td>0.70</td>
</tr>
<tr>
<td>Depth St From top</td>
<td>3.5 in</td>
<td>Mid-slab</td>
<td>4 in</td>
<td>3 – 4 in</td>
<td>Mid-slab</td>
<td>Mid-slab</td>
</tr>
<tr>
<td>Lane W</td>
<td>12 ft</td>
<td>12</td>
<td>14</td>
<td>12, 14</td>
<td>12</td>
<td>12, 14</td>
</tr>
</tbody>
</table>

*Summary of CRCP Design & Construction, CRSI, 2001*
## 1960’s Vs 2000’s

<table>
<thead>
<tr>
<th>Design</th>
<th>Illinois I-70 1960-70’s</th>
<th>Illinois I-70 2000’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Life &amp; Approx. ESALs</td>
<td>20 years 5 million ESALs</td>
<td>30 years 100 million ESALs</td>
</tr>
<tr>
<td>Expected Life &amp; ESALs*</td>
<td>Lasted 21-32 years until overlay, with 13 to 22 million ESALs</td>
<td>Design Guide predicts 40+ years and 140 million ESALs</td>
</tr>
<tr>
<td>Design</td>
<td>Illinois I-70 1960-70’s</td>
<td>Illinois I-70 2000’s</td>
</tr>
<tr>
<td>------------------------</td>
<td>-------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Pavement Type</td>
<td>CRCP</td>
<td>CRCP</td>
</tr>
<tr>
<td>Slab Thickness</td>
<td>8 in, 200 mm</td>
<td>12 in, 300 mm</td>
</tr>
<tr>
<td>Reinforcement %</td>
<td>0.63, #5 rebar</td>
<td>0.80, #7 coated rebar</td>
</tr>
<tr>
<td>Base type</td>
<td>4-in ATB</td>
<td>5-in HMA</td>
</tr>
<tr>
<td>Subbase type</td>
<td>None, on subgrade</td>
<td>Old CRCP “D” cracked</td>
</tr>
<tr>
<td>Shoulders</td>
<td>Asphalt</td>
<td>Tied PCC</td>
</tr>
</tbody>
</table>
Illinois Toll Road I-294 Chicago

A section of the Illinois Toll Road in Chicago was designed and constructed 2005 using the AASHTO ME Pavement Design Guide. A 12-in CRCP was required. The design ESALs were 200 million, 40 yrs.

- 12-in CRCP, Minimum cement factor 564 #/CY
- 0.75% steel
- Depth of steel 3.5-in
- Tied JPCP shoulder
- 4-in dense HMA base
- 12-in granular subbase
- Fine grained subgrade (A-6 soil)
Dan Ryan Expressway, I-94 Chicago, 2007
Illinois Dan Ryan Expressway I-94 Chicago

- Carries the largest volume of heavy trucks known in North America. Originally CRCP in 1961, it was reconstructed in 2006-7 for a 40 year life and was designed for nearly 500 million ESALs.
  - 14-in CRCP, Minimum cement factor 564 #/CY
  - 0.80% steel
  - Depth of steel 4.5-in
  - Tied JPCP shoulder
  - 4-in HMA dense base
  - 12-in granular subbase
  - Fine grained subgrade (A-6 soil)
Illinois “Extended Life Projects”

I-70 Marshall
Year 2002
30cm (12in) CRCP
13cm (5in) HMA
20 cm (8in) CRCP

I-80 Morris
Year 2003
36cm (14in) CRCP
15cm (6in) HMA
30cm (12in) CRCP

I-290 Schaumburg
Year 2003
36cm (14in) CRCP
15cm (6in) HMA
60cm (24in) Aggregate

I-74 Peoria
Year 2006
29cm (11.5in) CRCP
15cm (6in) HMA
30cm (12in) Aggregate
### Table 9 Design parameters for Route 210

<table>
<thead>
<tr>
<th>Attribute</th>
<th>20 YR JPCP</th>
<th>40 YR JPCP</th>
<th>100 YR JPCP</th>
<th>100 YR CRCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative truck traffic over design period</td>
<td>72 million</td>
<td>172 million</td>
<td>637 million</td>
<td>637 million</td>
</tr>
<tr>
<td>Flexural strength of PCC</td>
<td>626 psi</td>
<td>626 psi</td>
<td>725 psi</td>
<td>725 psi</td>
</tr>
<tr>
<td>PCC (in)</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>11 (0.75% steel)</td>
</tr>
<tr>
<td>Asphalt concrete base (in)</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Granular aggregate subbase (in)</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Design truck lane width (ft)</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
</tbody>
</table>
## LCCA Results for Route 210 CA
(no User or Environmental Costs calculated)

### Table 12: LCCA results for LA 210 (per lane-mile)

<table>
<thead>
<tr>
<th>Design Alternative</th>
<th>Discount Rate</th>
<th>Initial Construction</th>
<th>M&amp;R</th>
<th>Total*</th>
<th>% Relative to 100-Yr JPCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-Yr JPCP</td>
<td>(3%) (5%)</td>
<td>$2.35M</td>
<td>$0.49M</td>
<td>$2.84M</td>
<td>107.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$2.35M</td>
<td>$0.21M</td>
<td>$2.55M</td>
<td>97.0%</td>
</tr>
<tr>
<td>40-Yr JPCP</td>
<td>(3%) (5%)</td>
<td>$2.47M</td>
<td>$0.14M</td>
<td>$2.61M</td>
<td>98.9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$2.47M</td>
<td>$0.07M</td>
<td>$2.54M</td>
<td>96.3%</td>
</tr>
<tr>
<td>100-Yr JRCP</td>
<td>(3%) (5%)</td>
<td>$2.59M</td>
<td>$0.08M</td>
<td>$2.67M</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$2.59M</td>
<td>$0.05M</td>
<td>$2.64M</td>
<td>100.0%</td>
</tr>
<tr>
<td>100-Yr CRCP</td>
<td>(3%) (5%)</td>
<td>$2.79M</td>
<td>$0.00M</td>
<td>$2.79M</td>
<td>104.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$2.79M</td>
<td>$0.00M</td>
<td>$2.79M</td>
<td>105.7%</td>
</tr>
</tbody>
</table>

*Due to MEPDG limitations, RSL for both the 100-yr designs (JPCP and CRCP) has been assumed and not calculated, as in the case of 20- and 40-yr designs.*
20-cm CRCP, 0.85% longitudinal steel, placed 6-cm from the top. Transverse reinforcement placed at angle. Concrete strength high (674 lbs/cy cement, 90-day f’c mean 70 MPa. 6-cm bituminous base course. 8-20-cm lean concrete base over granular materials. **Over 100-km built, excellent performance!**
Antwerp Ring Road R1, 2005
Antwerp R1 CRCP

AADT = 200,000, 10 Lanes
AADTT = 50,000
325 million trucks over 40-years design lane
9-in CRCP, Asphalt Base
A12
A main highway between Holland and Germany 1998
A12 Motorway Netherlands Porous Asphalt/CRCP Composite Pavement

- Reconstructed in 1998 with a porous asphalt surfacing over a CRCP.
- 40-year design, 100,000 ADT
- Design
  - 5 cm (2-in) Porous Asphalt Friction Course
  - 25 cm (10-in) CRCP, 0.7% steel
  - 6 cm (2.5) dense AC base
  - 25 cm (10-in) cement bound recycled asphalt subbase
- 2.2 km long, 4 lanes wide
- Crack spacing: 0.8 – 3 m large majority
A12 Motorway Netherlands
A12 Netherlands AC/CRCP
No transverse cracks, 10 years
A73 CRCP Reinforcement, NL
## Design Feature Recommendations for Long-Life CRCP

<table>
<thead>
<tr>
<th>Design Feature</th>
<th>Recommendations for Long-Life CRCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab thickness</td>
<td>8 – 12 in (varies with traffic, climate &amp; design)</td>
</tr>
<tr>
<td>Reinforcement %</td>
<td>0.70 – 0.8 %</td>
</tr>
<tr>
<td>Depth reinforcement</td>
<td>Above mid depth</td>
</tr>
<tr>
<td></td>
<td>Typically 3.5 – 4.5 in from surface</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Tied concrete, or</td>
</tr>
<tr>
<td>Widened traffic lane</td>
<td>12 in max</td>
</tr>
</tbody>
</table>
## Recommendations Long Life CRCP

<table>
<thead>
<tr>
<th>Material Feature</th>
<th>Recommendations for Long-Life CRCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>Normal strength, &gt; 700 psi flexural, 28-days</td>
</tr>
</tbody>
</table>
| Aggregate type       | Lower coefficient of thermal expansion  
|                      | CTE < 6.5 / degree F               |
| Base course          | Hot-mixed asphalt (tested for stripping)  
|                      | (Do NOT prevent bonding with CRCP)  |
| Subbase course       | Granular layer (subdrainage)        
|                      | Or (CTB/Lean concrete + granular layer) |
## Recommendations Long Life CRCP

<table>
<thead>
<tr>
<th>Construction Item</th>
<th>Recommendations for Long-Life CRCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best time of placement</td>
<td>Cooler weather, afternoon or night</td>
</tr>
<tr>
<td>Worst time of placement</td>
<td>Hot, sunny morning</td>
</tr>
<tr>
<td>Curing</td>
<td>Under sunny conditions, keep surface cool by water spray for day to avoid large built in temperature gradient</td>
</tr>
<tr>
<td>Contact friction with base</td>
<td>Concrete/asphalt friction is ideal. Do not break bond.</td>
</tr>
<tr>
<td>Composite HMA/CRCP</td>
<td>New or overlay, no reflection cracking, increases life of HMA surface, use if studded tires exist (R&amp;R HMA over time)</td>
</tr>
</tbody>
</table>
Questions?