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Summary of CRCP Design and Construction Practices in the U.S.

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INTRODUCTION

To date, over 28,000 lane-miles of continuously reinforced concrete pavement (CRCP) have been built in the U.S. More than 35 states have built CRCP, at least on trial basis. This report reviews the current CRCP design and construction practices in Illinois, Oklahoma, Oregon, South Dakota, Texas, and Virginia. Most of the new CRCP in the U.S. is currently built in these states.

The data published in this report is based on information furnished to ERES Consultants by the states in 2000. This summary should not be construed as an endorsement of any or all of the states' practices for designing, specifying, and building continuously reinforced concrete pavement.

Design Procedure

All of the states surveyed in this study use the 1986/1993 AASHTO design procedures, except Illinois and Texas, which use modified versions of the AASHTO procedures. The objective of the AASHTO CRCP design procedure is to determine the amount of longitudinal reinforcing steel that satisfies the criteria of crack spacing, crack width, and steel stress.

The AASHTO procedure for determining the thickness of CRCP is the same as that for jointed concrete pavements. Illinois reduces the CRCP slab thickness determined by the AASHTO procedure by 20 percent to account for the effects of the steel.

The CRCP design procedure in the AASHTO 2002 mechanistic-empirical design guide will involve selecting the design features that ensure that the pavement will meet the performance criteria (punchouts per mile and International Roughness Index [IRI]) at an acceptable level of reliability.

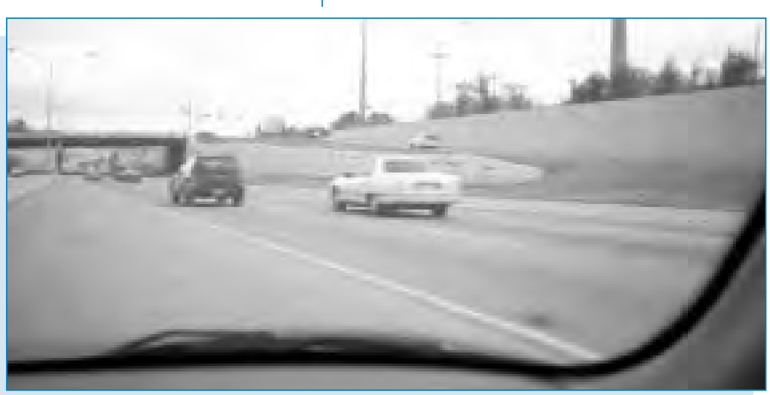
The AASHTO 2002 Guide is currently under development.

Allowable Crack Width

The maximum allowable transverse crack width is used to determine the required amount of longitudinal steel. Smaller crack widths generally increase the capacity of the slab for transferring repeated shear stresses (caused by heavy axle loads) between adjacent slab segments.

Wider cracks generally exhibit lower load transfer efficiency, which can result in increased load-related tensile stresses at the top of the slab, followed by the development of longitudinal cracks and punchouts. Tight cracks are particularly important in regions where deicing salts are used because wider cracks increase the possibility of corrosion of the reinforcing steel.

All studied states except Texas use the AASHTO-recommended maximum allowable crack width of 0.04 inches. Texas uses a limiting crack width of 0.025 inches. A maximum design crack width of 0.02 inches is desired to protect against spalling and water penetration.



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Slab Thickness

In general, as the slab thickness of CRCP increases, the capacity to resist critical bending stresses increases, as does the slab's capability to transfer load across the transverse cracks. Consequently, as slab thickness increases, punchouts decrease and smoothness increases.

Illinois data show that slab thickness and amount of longitudinal steel are the most significant design features in terms of effect on CRCP performance. For example, by 2001, the CRCP portion of Edens Expressway (I-94) in Chicago (built in 1980 using a 10-inch slab and 0.71 percent steel) had carried over 25 million equivalent single axle loads (ESALs), and exhibits few punchouts.

Table 1 shows that the slab thickness in the studied states ranges between 8 and 15 inches. Texas has the widest range of slab thickness (8 to 15 inches), whereas Virginia has the tightest range (10 to 11 inches). Illinois requires a minimum CRCP slab thickness of 10 inches for the Interstate system; most CRCP on the Illinois Interstate system now has a slab thickness of 10 to 13 inches.

Table 1

	SLAB THICKNESS RANGES
Illinois	10 in. *(minimum on Interstates)*
Oklahoma	9 – 12 inches
Oregon	8 – 12 inches
South Dakota	8 – 11 inches
Texas	8 – 15 inches
Virginia	10 – 11 inches

Lane Width and Shoulder Type

Lane width is typically synonymous with lane slab (usually 12 feet). Field and analytical studies have shown that a wider slab keeps truck axles away from the free edge (shoulder edge), greatly reducing bending stresses and deflections and consequently reducing the occurrence of edge punchouts.

Generally, a slab should not be widened without full consideration of other design features such as shoulders. Usually, shoulders don't have any significant structural value unless major efforts are made to increase the long-term load transfer of the lane/shoulder joint and reduce the erodibility of the underlying base materials of the shoulder.

Table 2 shows the lane width and shoulder type used in the studied states. South Dakota, Oregon and Virginia allow for using widened lanes (14 feet), whereas the remaining states use the standard 12-foot-lane only. South Dakota and Virginia use both PCC and asphalt concrete (AC) shoulders, whereas the remaining states use PCC shoulders. CRCP shoulders are sometimes used.

Table 2

	OUTSIDE SHOULDER TYPE	LANE WIDTH
Illinois	PCC	12 feet
Oklahoma	PCC *(doweled in urban areas)*	12 feet
Oregon	AC	14 feet
South Dakota	AC or PCC	12 or 14 feet
Texas	Same as travel lane	12 feet
Virginia	AC or PCC	12 or 14 feet

AC = asphalt; PCC = concrete

PCC Strength

As portland cement concrete (PCC) strength increases, a greater fatigue life typically results. However, since the modulus of elasticity also increases with increased strength, the increase in fatigue life is generally not as dramatic as commonly believed (due to a corresponding increase in brittleness).

Table 3 shows the concrete design strength and the testing method in the studied states.

Illinois uses 14-day tests, whereas the remaining states use 28-day tests. It is interesting to note the range of design strength values.

Aggregates

Aggregate type and size affects the properties of the PCC mix (strength, thermal coefficient of expansion, and drying shrinkage).

Table 4 shows the primary aggregate types and the maximum aggregate size used in the studied states.

Base

Base materials, erodibility, bonding to the PCC slab, and base width are critical features that affect cluster cracking, and loss of support (erosion), and thus punchouts and smoothness of CRCP.

Table 5 shows the base type, thickness, and specified permeability in the studied states. It can be seen that the states use a variety of base types and a wide range of thicknesses (4 to 8 inches); however, most do not use permeable bases.

Table 3

	PCC STRENGTH	DESIGN VALUE
Illinois	14-day compressive strength	3,500 psi
	14-day flexural strength	650 psi
Oklahoma	28-day compressive strength	3,000 psi
Oregon	28-day compressive strength	4,000 psi
South Dakota	28-day compressive strength	4,000 psi
Texas	28-day 3rd point flexural strength	650 psi
Virginia	28-day compressive strength	3,000 psi

psi = pounds per square inch

Table 4

	AGGREGATE TYPE	MAXIMUM SIZE
Illinois	Gravel, crushed gravel, concrete, stone, concrete slag, or sandstone	1.5 inches
Oklahoma	Crushed limestone	1.5 inches
Oregon	Crushed basalt	1.5 inches
South Dakota	Quartz, limestone, and granite	1.0 inches
Texas	Limestone and siliceous river gravel	0.75 – 1.5 inches
Virginia	Various non-polished aggregates	AASHTO 357 *100% passing 2.0-in. sieve*

Table 5

	BASE TYPE	PERMEABILITY	THICKNESS
Illinois	Bituminous-aggregate Mix	Not Permeable	4.0 inches
Oklahoma	ATB, OGDB, Econocrete	Sometimes	4.0 inches
Oregon	ATB or Granular base	Sometimes	ATB 4.0 inches Granular 6.0 in.
South Dakota	Granular, CTB with HMA breaker, and ATB	Not Permeable	6.0 inches
Texas	CTB with HMA breaker, and ATB	Not Permeable	CTB 6.0 inches ATB 4.0 inches
Virginia	CTB	Permeable	6.0 – 8.0 inches

ATB = Asphalt-treated base
OGDB = Open-graded drainable base
CTB = Cement-treated base
HMA = Hot-mix asphalt

Subgrade Improvement

The improvement of a soft wet subgrade provides improved and uniform support to the pavement and aids construction.

As shown in **Table 6**, subgrade improvement in the studied states is accomplished by stabilizing the upper portion with lime or cement. South Dakota does not stabilize the subgrade.

Table 6

SUBGRADE IMPROVEMENT

Illinois	Lime modification
Oklahoma	Stabilized subgrade
Oregon	Remove problem areas and fill with granular materials
South Dakota	None
Texas	6 - 8 inches of lime stabilization
Virginia	Soil cement stabilization (occasionally)

Steel Reinforcement

The amount and depth of longitudinal reinforcing steel are the most important aspects of steel reinforcement in CRCP because it affects transverse crack spacing and controls the width of the cracks. Field studies have shown that longer crack spacing increases the potential for wider transverse cracks.

Reinforcing steel content should be determined with consideration of climatic conditions and several design features, including slab thickness, maximum allowable crack width, PCC material properties, and base type and stiffness.

Illinois CRCP data have shown that increased reinforcing steel content results in less distress and increased smoothness. In the United States, longitudinal steel percentages of 0.55 to 0.70 have provided suitable cracking patterns and performance in CRCP systems. In Europe, a longitudinal steel percentage of up to 0.85 has provided suitable cracking patterns and performance.

Field studies have shown that the closer the reinforcing steel is to the slab surface, the tighter the cracks remain and the fewer punchouts develop over time. However, at least 3 inches of cover is needed to account for construction tolerances and to keep chlorides from reaching the steel.

Other aspects of reinforcing steel include placement method, steel grade, epoxy coating, and amount of transverse steel. **Table 7** summarizes the steel reinforcement parameters in the studied states.

Table 7

STEEL REINFORCEMENT

	Longitudinal Steel %	Steel Grade	Use of Epoxy Coating	Depth of Steel	Steel Placement Method	Transverse Steel
Illinois	0.7	60, 40(1)	Chicago area only	3.5 in.	Chairs	#4 bars at 48-inch spacing (0.04% max.)
Oklahoma	0.71 - 0.73	60	In urban areas	mid-slab	Chairs and tubes	#5 bars at 44-inch spacing
Oregon	0.6 – 0.7	60	No	4.0 in.	Chairs	#4 bars at 36-inch spacing
South Dakota	0.7	60	No	3 to 4 in.	Chairs	0.15%
Texas	0.4-0.5(2) 0.71-0.78	60	No	mid-slab *(2 layers of steel if slab thickness is ≥ 13 in.)*	Chairs	#5 or #6 bars at 30 to 36-inch spacing (based on slab thickness and width)
Virginia	0.7	60	No	mid-slab (±0.5 in.)	Chairs	#5 bars at 48-inch spacing

(1) Grade 60 for longitudinal steel and Grade 40 or 60 for transverse steel.
(2) 0.4–0.5 for 8-in. slabs, 0.71–0.78 for 15-in. slabs, and interpolate in-between.

Construction

Construction factors such as time of PCC placement, curing method, construction joints, terminal joints, and reinforcing steel placement affect the long- term performance of CRCP. Field studies concluded that early CRCP failures are usually associated with insufficient lapping of reinforcing steel, unconsolidated concrete around the steel (particularly at transverse construction joints, which require additional amounts of longitudinal steel), improper position of the steel in the slab, and extremely hot weather during construction.

Concrete Placement Time and Curing

Typically, CRCP placed in cool weather conditions performs better (longer crack spacing and smaller crack width) than CRCP placed in hot weather conditions. CRCP placed in the fall can develop shorter crack spacing (less desirable) than CRCP built in the spring, due to relatively lower concrete strength development, that is caused by lower air temperatures.

Transverse crack formation is also related to the time of the day the concrete is placed. Concrete placed in the morning generally has shorter crack spacings (less desirable) than concrete placed in the afternoon. CRCP built later in the day tends to perform slightly better than CRCP built in the morning.

Curing reduces the moisture loss from the PCC mixture during the hardening process and reduces temperature variation. Thus, proper curing of CRCP is critical to minimizing the potential of early cracking.

Table 8 shows the construction time and concrete curing methods used by the studied states.

Table 8

	SEASON	TIME	CURING METHOD
Illinois	Not specified	Not specified	Wet cure or Type III drying compound
Oklahoma	All year (except extreme cold)	Day	White resin-based wax curing compound
Oregon	All year	Day or night	Curing compound
South Dakota	Spring, Summer, & Fall	Day	White pigmented curing compound
Texas	All year	Day or night	Curing compound (2 coats)
Virginia	Spring, Summer, & Fall	Day	Curing compound (2 coats)

Construction Joints and Terminals

Only Virginia and Texas still use anchor lugs where CRCP abuts either a structure or a different pavement type in order to restrict the movement experienced by the CRCP. Several studies conducted in Illinois and other states concluded that a steel wide-flange beam provides a cost-effective method for accommodating the movements at the ends (terminals) of the CRCP.

An important factor in good CRCP performance is continuity—specifically steel continuity. Thus, several states use extra reinforcing steel at transverse construction joints to ensure continuity.

Table 9 describes the specifications for CRCP construction joints and terminals in the studied states.

SUMMARY

This study compares the current highway design and construction practices for continuously reinforced concrete pavement in the states of Ilinois, Oklahoma, Oregon, South Dakota, Texas and Virginia. The practices listed encompass those factors that have the greatest influence on the long-term performance of CRCP. A synoptic table of state practices is provided on page 8.

States not as familiar with CRCP can benefit from the experiences that have been gained through research, testing, and construction by these six states, and others, to develop with confidence their own CRCP project designs, specifications, and construction practices.

Table 9

	CONSTRUCTION JOINT	TERMINAL
Illinois	Additional #6 bars, 72-inches long, placed adjacent to every other longitudinal bar	Wide-flange beam
Oklahoma	Additional 72-inch-long bars placed adjacent to every other longitudinal bar. Same diameter as longitudinal	Sleeper slab
Oregon	No extra steel	Wide-flange beam
South Dakota	Additional #6 bars, 72-inches-long, placed adjacent to every other longitudinal bar	Manufactured beam embedded in a sleeper slab
Texas	Slab thick $\leq$ 9 inches: 72-inch-long bars placed adjacent to every other longitudinal bar Same diameter as longitudinal steel. Slab thick > 9 inches: No extra steel.	Occasionally use anchor lugs, but moving toward using wide-flange beam
Virginia	Additional 72-inch-long bars placed adjacent to every other longitudinal bar Same diameter as longitudinal steel	Anchor slab

Design/Construction Features of CRCP

	Illinois	Oklahoma	Oregon	South Dakota	Texas	Virginia
Design Procedure	modified AASHTO	AASHTO	AASHTO	AASHTO	modified AASHTO	AASHTO
Design Crack Width, inches	not specified	0.04	0.04	0.04	0.025	not specified
Slab Thickness, inches	10 (min. on Interstate)	9–12	8–12	8–11	8–15	10–11
Outside Lane Width, feet	12	12	14	12 or 14	12	12 or 14
PCC Strength Measurement Method	14-day comp. & flexural strength	28-day compressive	28-day compressive	28-day compressive	28-day flexural 3rd point	28-day compressive
PCC Strength, psi	3,500 comp. 650 flexural	3,000 comp. (Class A PCC)	4,000 comp.	4,000 comp.	650 flexural	3,000 comp.
Primary Aggregate Type	gravel, crushed gravel, stone, concrete, slag or sandstone	crushed limestone	crushed basalt	quartzite, limestone, granite	limestone, and siliceous river gravel	various non-polished
Maximum Aggregate Size, inches	1.5	1.5	1.5	1.0	0.75–1.5	AASHTO 357 (100% passing 2.0-in. sieve)
PCC Curing Method	wet cure or Type III cur. comp.	white resin based wax curing comp.	curing compound	white pigmented curing compound	2 coats of curing compound	curing compound
Placement Season	not specified	all year (except extreme cold)	all year	Spring, Summer, Fall	all year	Spring, Summer, Fall
Placement Time of Day	not specified	day	day or night	day	day or night	day
Base Type [1]	BAM	ATB, OGPB, Econocrete	ATB or Granular	Granular, CTB with HMA breaker, ATB	CTB with HMA breaker, ATB	CTB
Permeable Base	no	sometimes	sometimes	no	no	yes
Base Thickness, inches	4	4	ATB: 4 Granular: 6	Granular: 6	CTB: 6 ATB: 4	6 – 8
Improved Subgrade	lime modification	stabilization	remove prob. areas & fill w/granular mat'l	none	6–8 in. lime stabilization	occasional soil cement stabilization
Outside Shoulder Type [1]	PCC	plain PCC (doweled in urban areas)	AC	AC or PCC	Same as travel lane	AC or PCC
Amount of Longitudinal Steel, %	0.7	0.71–0.73	0.6–0.7	0.7	8-in. slab: 0.4–0.5 15-in. slab: 0.71–0.78	0.7
Steel Grade, ksi	Long: 60 Transv: 40 or 60	60	60	60	60	60
Steel Placement Method	Chairs	Chairs or Tube-fed	Chairs	Chairs	Chairs	Chairs
Epoxy Coated Steel	In Chicago area only	urban: yes rural: no	no	no	no	no
Depth of Steel (from slab surface), inches	3.5	mid-slab	4.0	3.0–4.0	mid-slab (2 layers if >13" thick)	mid-slab (± 0.5 inches)
Amount of Transverse Steel	#4 bars at 48-in. spacing (0.04% max)	#5 bars at 44-in. spacing	#4 bars at 36-in. spacing	0.15%	#5 or #6 bars at 30-36 in. spacing	#5 bars at 48-in. spacing
Construction Joint Design	additional #6 bars [2]	[2]	no extra steel	additional #6 bars [2]	if slab ≤ 9 inches then [2]	[2]
Terminal Design	wide-flange beam	sleeper slab	wide-flange beam	manufactured beam embedded in a sleeper slab	occasionally use anchor lugs, but moving toward wide-flange beam	anchor slab

[1] *BAM = Bituminous-Aggregate Mix; ATB = Asphalt-treated base; OGDB = Open-Graded Drainable Base; CTB = Cement-Treated Base; HMA = Hot Mix Asphalt*

[2] *Additional 72-inch-long bars placed adjacent to every other longitudinal bar (same diameter as longitudinal steel), unless noted.*

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