PERFORMANCE OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS IN OKLAHOMA - 1996

Final Report
August 1996

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Beginning in the early 1970s, over 1104 lane km (686 lane miles) of continuously reinforced concrete pavements (CRCP) were constructed Oklahoma, with almost 75 percent constructed since 1986. There have been three distinct design periods in the state, with a lower percentage of longitudinal reinforcing used in pavements constructed between 1985 and 1990. This study investigated the performance of the state's CRCP, focusing on crack spacing, occurrence of cluster cracking, and overall pavement condition. A comparison was also made between design and construction methods used by the Oklahoma Department of Transportation and the Texas Department of Transportation.

This investigation found overall good performance of the state's CRCP when compared to other states. Visual surveys of 44 projects revealed an average of 1.1 punchouts or patches per mile with four projects exhibiting a large number of distresses. Factors were identified for each of these four projects (i.e., age, structural design, or type of base material) that have likely affected their performance.

Recommendations were made to monitor newer pavements that have exhibited poor cracking patterns, to adopt the use of an asphalt bond breaker between the CRCP and cement-treated base or decrease the cement content of the base, to saw and seal longitudinal construction joints between the PCC shoulders and CRCP, and to consider increasing the percentage longitudinal reinforcing and the outside lane width.

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CRCP, Continuously reinforced concrete pavements, performance, pavement distresses, crack spacing

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Approximate Conversions to SI Units					*Approximate Conversions from SI Units*				
Symbol	**When you know**	**Multiply by**	**To Find**	**Symbol**	**Symbol**	**When you know**	**Multiply by**	**To Find**	**Symbol**
		LENGTH					LENGTH		
in	inches	25.40	millimeters	mm	mm	millimeters	0.0394	inches	in
ft	feet	0.3048	meters	m	m	meters	3.281	feet	ft
yd	yards	0.9144	meters	m	m	meters	1.094	yards	yd
mi	miles	1.609	kilometers	km	km	kilometers	0.6214	miles	mi
		AREA					AREA		
in^2	square inches	645.2	square millimeters	mm	mm^2	square millimeters	0.00155	square inches	in^2
ft^2	square feet	0.0929	square meters	m^2	m^2	square meters	10.764	square feet	ft^2
yd^2	square yards	0.8361	square meters	m^2	m^2	square meters	1.196	square yards	yd^2
ac	acres	0.4047	hectares	ha	ha	hectares	2.471	acres	ac
mi^2	square miles	2.590	square kilometers	km^2	km^2	square kilometers	0.3861	square miles	mi^2
		VOLUME					VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.0338	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.2642	gallons	gal
ft^3	cubic feet	0.0283	cubic meters	m^3	m^3	cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.7645	cubic meters	m^3	m^3	cubic meters	1.308	cubic yards	yd^3
		MASS					MASS		
oz	ounces	28.35	grams	g	g	grams	0.0353	ounces	oz
lb	pounds	0.4536	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)					TEMPERATURE (exact)		
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C	°C	degrees Celsius	9/5(°C)+32	degrees Fahrenheit	°F
		FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS		
lbf	poundforce	4.448	Newtons	N	N	Newtons	0.2248	poundforce	lbf
lbf/in^2	poundforce per square inch	6.895	kilopascals	kPa	kPa	kilopascals	0.1450	poundforce per square inch	lbf/in^2

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TABLE OF CONTENTS

LIST OF TABLES

EXECUTIVE SUMMARY

Beginning in the early 1970s, over 1104 lane km (686 lane miles) of continuously reinforced concrete pavements (CRCP) were constructed in Oklahoma, with almost 75 percent constructed since 1986. There have been three distinct design periods in the state, with a lower percentage of longitudinal reinforcing used in pavements constructed between 1985 and 1990. This study investigated the performance of the state's CRCP, focusing on crack spacing, occurrence of cluster cracking, and overall pavement condition. A comparison was also made between design and construction methods used by the Oklahoma Department of Transportation and the Texas Department of Transportation.

This investigation found overall good performance of the state's CRCP when compared to other states. Visual surveys of 44 projects revealed an average of 1.1 punchouts or patches per mile with four projects exhibiting a large numbers of distresses. Factors were identified for each of these four projects (i.e., age or type of base material) that would likely have affected their performance.

Recommendations were made to monitor newer pavements that have exhibited poor cracking patterns, to adopt the use of an asphalt bond breaker between the CRCP and cement-treated base or decrease the cement content of the base, to saw and seal longitudinal construction joints between the PCC shoulders and CRCP, and to consider increasing the percentage longitudinal reinforcing and the outside lane width.

PERFORMANCE OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS IN OKLAHOMA - 1996

INTRODUCTION

The Office of Research at the Oklahoma Department of Transportation (ODOT) was asked to investigate the performance of the state's continuously reinforced concrete pavements (CRCP). Specific items of concern were crack spacing, occurrence of cluster cracking, and overall condition of the state's CRC pavements. It was also requested that the Office of Research investigate the CRCP design and construction methods used by the Texas Department of Transportation (TxDOT).

There are currently over 1104 lane km (686 lane miles) of CRCP in the state of Oklahoma, with almost 75% constructed in the last ten years. CRC pavements are located primarily in the eastern half of the state with few in western Oklahoma. The first CRC pavements were constructed in the state in the early- to mid-1970s using 0.6 percent longitudinal reinforcing steel. CRCP was not used in Oklahoma again until the mid-1980s when CRCP was constructed using 0.5 percent longitudinal steel. Beginning about 1990, the longitudinal steel was increased to 0.6 percent in CRC pavements built in the state. Oklahoma's earliest CRC pavements were constructed with fine aggregate bituminous bases and asphalt shoulders while the 1980s pavements typically had 76 to 102 mm (3 to 4 inches) of an asphalt base and tied PCC shoulders [1]. The most recent CRCP have been built with an open graded, cement-treated base and tied PCC shoulders. A summary of state CRCP projects is given in Table 1.

TRANSVERSE CRACK SPACING IN CRCP

CRCP develops transverse cracks whenever induced tensile stresses due to shrinkage, temperature, or load, exceed the tensile strength of the concrete. Cracking begins within a few days following construction and continues for the life of the pavement, with most of the cracks having formed within the first few years [2, 3]. Spacing of cracks and crack width are important variables in the behavior and performance of CRC pavements [2, 3, 4]. The American Association of State Highway Transportation Officials (AASHTO) recommends that crack spacing be limited to no less than 1.07 m (3.5 feet) to minimize potential for punchout and no more than 2.44 m (8 feet) to minimize crack spalling [5, 6].

Table 1. Summary of Oklahoma CRCP Projects.

County	Project Number	Hwy.	Div.	Year Compl.	Pav. Th.	% Long. Steel	% Trans. Steel	Shldr.	Base	Punchouts/ Patches/km	Punchouts/ Patches/mile
ATOKA1	F-299(35)	U.S. 69	2	1988	9"	0.50	0.08	PCC	3" Type C AC	1.9	3.0
ATOKA2	F-299(45)	U.S. 69	2	1988	9"	0.50	0.08	PCC	3" Type C AC	0.9	1.5
ATOKA3	F-299(99)	U.S. 69	2	1990	10"	0.61	0.07	PCC	3" Type A AC	0.0	0.0
BECKHAM	IM-40-2(119)	I-40	5	1993	10"	0.61	0.07	PCC	4" OGPC	0.1	0.2
BRYAN	F-219(35)	U.S. 69/75	2	1985	9"	0.50	0.08	PCC	6" Soil Asphalt	4.2	6.8
CARTER1	I-35-1(48)	I-35	7	1970	8"	0.61	0.08	AC	4" FABB	0.9	1.5
CARTER2	I-35-1(53)	I-35	7	1971	8"	0.61	0.08	AC	4" FABB	0.3	0.5
CHEROKEE	STP-11B(334)	U.S. 62	1	1996	9"	0.61	0.08	PCC	4" OGPC	under constr.	under constr.
CIMARRON	MAF-350(11)	U.S. 287/64	6	1996	10"	0.61	0.07	CRCP	4" OGPC	under constr.	under constr.
COMANCHE	MAM-7780(002)	Rogers Ln.	7	1992	9"	0.61	0.08	curb	6" Type B AC	not collected	not collected
LOGAN (1)	IR-35-4(115)	I-35	4	1989	10"	----	0.11	PCC	3" Type A AC	0.1	0.1
MAYES1	F-398(35)	U.S. 412	8	1991	10"	0.61	0.07	PCC	4" Type A AC	0.1	0.2
MAYES2	F-194(45)	U.S. 412	8	1987	9"	0.50	0.08	PCC	3.5" Type A AC	0.1	0.1
MAYES3	F-593(252)	U.S. 69	8	1991	10"	0.61	0.11	PCC	3" Type A AC	0.2	0.3
MURRAY	I-35-2(64)	I-35	7	1971	8"	0.61	0.08	AC	4" FABB	0.6	0.9
MUSKOGEE1 (2)	I-40-6(86)	I-40	1	1973	8"	0.61	None	AC	4" FABB	3.7	5.9
MUSKOGEE2	MABRF-593(241)	U.S. 69	1	1990	10"	0.51	0.11	PCC	2" Type B AC	1.1	1.7
MUSKOGEE3	STP-404(66)	U.S. 62	1	1993	9"	0.61	0.08	PCC	4" OGPC	0.0	0.0
MUSKOGEE4	SAP-51(392)	U.S. 69 & 64	1	1996	10"	0.61	0.07	PCC	4" OG	under constr.	under constr.
MUSKOGEE5	STP-51B(360)	U.S. 62	1	1996	9"	0.61	0.08	PCC	4" OGPC	under constr.	under constr.
MUSKOGEE6	MAFEGC-410(35)	S.H. 165	1	1987	9"	0.50	0.08	PCC	4" Type A AC	0.0	0.0
NOBLE (3)	MAIR-35-4(111)	I-35	4	1990	10"	0.61	0.11	PCC	4" Econocrete	0.2	0.3
OKFUSKEE (4)	IR-40-5(169)	I-40	3	1986	9"	0.50	0.08	PCC	4" CABB	3.7	6.0
OKLAHOMA1	I-IR-35-3(110)	I-35	4	1993	10"	0.61	0.07	CRCP	4" OGBB	0.0	0.0
OKLAHOMA2	IR-35-3(049)	I-35	4	1994	10"	0.61	0.07	CRCP	4" OG	0.0	0.0
OKLAHOMA3	F-385(043)	S.H. 74	4	1992	10"	0.61	0.07	PCC	4" OGBB	0.0	0.0
OKLAHOMA4	F-385(055)	S.H. 74	4	1992	10"	0.61	0.07	PCC	4" OG	0.0	0.0
OKLAHOMA5	IM-NHIY-35-3(219	I-35	4	1995	10"	0.61	0.07	CRCP	4" OG	0.0	0.0
OKLAHOMA6	MAF-385(054)	S.H. 74	4	1992	10"	0.61	0.07	PCC	4" OG	0.0	0.0
OKMULGEE	MABRF-53(141)	U.S. 62/75	1	1991	9"	0.50	0.08	PCC	3" Type B AC	0.3	0.4
PITTSBURG1	F-186(183)	U.S. 69	2	1991	10"	0.61	0.07	PCC	4" OGPC	0.0	0.0
PITTSBURG2 (5)	MAF-186(185)	U.S. 69	2	1991	10"	0.61	0.07	PCC	4" OGPC	0.0	0.0
PITTSBURG3	DPIY-204(001)	U.S. 69	2	1994	10"	0.61	0.07	PCC	4" OGPC	0.0	0.0
PITTSBURG4	MAF-186(180)	U.S. 69	2	1993	10"	0.61	0.07	PCC	4" OGPC	0.0	0.0
PONTOTOC	MAF-235(009)	S.H. 3W	3	1990	10"	0.61	0.07	PCC	4" Type A AC	0.0	0.0
ROGERS1	MAF-194(35)	U.S. 412	8	1986	9"	0.50	0.08	PCC	Select	0.0	0.0
ROGERS2	STP-66B(306)	U.S. 169	8	1995	10"	0.61	0.07	PCC	4" OG	0.0	0.0
SEQUOYAH1	IR-40-6(220)	I-40	1	1991	10"	0.61	0.07	PCC	4" OGPC	0.6	0.9
SEQUOYAH2	IR-40-6(222)	I-40	1	1989	10"	0.51	0.11	PCC	4" Econocrete	0.0	0.0
TULSA1	I-244-2(101)	I-244	8	1973	8"	0.61	0.08	AC	5" FABB	not collected	not collected
TULSA2	I-244-2(108)	I-244	8	1974	8"	0.61	0.08	AC	5" FABB	4.7	7.5
TULSA3	MAF-521(075)	U.S. 169	8	1990	9"	0.61	0.08	PCC	4" Type A AC	0.0	0.0
TULSA4	F-15(218)	U.S. 75	8	1990	9"	0.61	0.08	CRCP	4" Type A AC	0.0	0.0
TULSA5	IR-44-2(328)	I-44	8	1991	12"	0.60	0.06	PCC	4" OCPC	0.1	0.2
TULSA6	ACIR-44-2(326)	I-44	8	1994	10"	0.61	0.07	CRCP	10" AC	0.0	0.0
TULSA7	RS-7248(100)	S.H. 67	8	1994	10"	0.61	0.07	PCC	4" OG	0.0	0.0
TULSA8	STPY-72C(404)	S.H. 67	8	1994	10"	0.61	0.07	PCC	4" OG	0.0	0.0
WASHINGTON1	MAF-15(209)	U.S. 75	8	1989	9"	0.50	0.08	PCC	2" Type B AC	0.1	0.1
WASHINGTON2	MAF-15(211)	U.S. 75	8	1990	10"	0.51	0.11	PCC	Type B AC	0.1	0.1
WASHINGTON3	F-15(213)	U.S. 75	8	1990	10"	0.61	0.07	PCC	Type B AC	0.1	0.1
WASHINGTON4	NH-481(69)	U.S. 75	8	1997	10"	0.61	0.07	PCC	varies	under constr.	under constr.

(1)NOTE: 0.51% Epoxy-Coated Long. Reinf. Northbound, 0.61% Plain Southbound.
(2)NOTE: No Transverse Reinforcing. (Pederson, 1976)
(3)NOTE: Epoxy-Coated Northbound Only.
(4)NOTE: No Transverse Steel Westbound. (Borg, 1991)
(5)NOTE: Includes a SHRP Test Section using 0.7% long. steel.

Longitudinal steel in CRCP is designed to maintain crack closure to prevent the infiltration of water or incompressibles and allow load transfer by aggregate interlock [7, 8]. In general, the amount of longitudinal reinforcement is highly correlated to crack spacing and crack width, with a larger percentage of steel producing a closer crack spacing and smaller crack width [7, 9, 10]. However, Zollinger found that "while crack spacing could be controlled to some extent by the amount of reinforcing steel used and steel placement, the dominant factor in crack spacing appeared to be climatic conditions at the time of construction" [11].

Crack widths are significantly affected by time of crack occurrence, construction season (ambient temperature), type of coarse aggregate, and amount of steel. Early age cracks (formed during the first three days after construction) have been found to be "significantly wider than those which occurred later," and tend to meander, increasing the probability of intersecting cracks and punchouts. Large variations in temperature (due to the combined heat of hydration and high ambient temperature followed by subsequent cooling at night) during the 24 hours immediately following construction is the primary cause of early-age cracks [10]. CRCP placed during hot weather was found to have much wider cracks than that placed during cool weather. The use of siliceous river gravel for coarse aggregate produced wider cracks than those using limestone [12]. Factors affecting crack spacing include the bond strength between the concrete and the reinforcing steel and the vertical placement of longitudinal steel within the slab [13].

CLUSTER CRACKING AND OTHER CRCP DISTRESSES

Cluster cracking, a grouping of three or more closely spaced transverse cracks, can be the sign of a potential problem in CRCP. Any abnormal increase in the amount of transverse cracking, especially when accompanied by an increase in spalling, can also be a sign of problem development. Cluster cracking has been associated with variation in subgrade support, poor concrete consolidation, inadequate drainage, high base friction, and high ambient temperature at time of construction [7].

Punchouts are the major form of structural distress commonly associated with CRCP [3,7]. Excessive deflections (due to reduced base support) under repeated heavy loads breakdown the aggregate interlock across cracks and eventually rupture the steel to form a punchout. Punchouts are typically associated either with close crack spacings or "Y" cracks. Longitudinal cracking is not typical in CRCP but does not usually present problems. In cases where longitudinal cracks become progressively wider and spalled, it can signify the beginning of foundation settlement problems. In addition, longitudinal cracking will occur during the formation of punchouts. Diagonal and "Y" cracking are also thought to be indicative of foundation problems [7].

Premature failures in CRCP have been associated with insufficient lap of steel reinforcement, unconsolidated concrete around steel reinforcement (particularly at construction joints), improper position of steel in the slab, two-course concrete construction (causing laminations at the level of steel placement), and problems associated with hot weather construction or improper terminal anchorages [14]. McCullough and Chesney observed the greatest number of failures in areas "where 0.5 percent longitudinal steel was used and high curing temperatures were experienced" [15].

CONDITION OF CRCP IN OKLAHOMA

FHWA 1988 Survey

In July 1988, a visual survey of selected PCC projects was made by Bill Barton and Chuck Boyd of the Federal Highway Administration (FHWA). They noted that I-40 near Warner in Muskogee County (0.61 percent steel) was over 15 years old and performing well. Two projects (Bryan and Atoka Counties) using 0.50 percent longitudinal steel exhibited wide transverse cracks [16].

ODOT Research 1990 Survey

Visual and roughness surveys were performed by ODOT Research personnel on all CRCP projects in April 1990 and a CRCP database was compiled in 1991. The resulting Research report from March 1991 found "the overall condition of the CRCP in Oklahoma to be good, based on the roughness survey and visual observations"[1]. Problems were noted in Bryan County where it was felt that use of a soil asphalt base led to cluster cracking and the eventual formation of punchouts. Cluster cracking was common on most of the projects but had not resulted in many failures except in Bryan County. Construction joints and wide flange terminal joints were generally in poor condition.

OSU 1990 Crack Survey

Dr. Farrel Zwerneman of Oklahoma State University surveyed I-35 in Logan and Noble Counties in August 1990 for a study of the use of epoxy-coated reinforcing in CRCP. Results of those surveys indicated that the average crack spacing was between 1.5 and 2.1 m (five and seven feet). The pavements constructed with epoxy-coated steel (northbound lanes on both projects) had slightly closer average crack spacing than those constructed with uncoated steel [14].

ODOT and FHWA 1991 Survey

In April 1991, a visual survey of 20 CRCP projects was made by Tim Borg of ODOT, Frank Cunningham of the American Concrete Pavement Association, and Bill Barton of the FHWA. The results of the survey noted that Atoka County had wide cracks with some spalling and Bryan County (using a soil asphalt base) had numerous punchouts. Muskogee County near Warner (constructed in 1972 with no transverse steel [17]) had closely spaced cracks with seven punchouts in the eastbound lane and many repairs in the westbound lanes. Murray County (constructed in 1970) had four punchouts and Logan County had larger crack spacing northbound (epoxy-coated rebar) than southbound (plain rebar) with no punchouts noted. Okfuskee County (constructed in 1987 with no transverse steel westbound) had eight punchouts westbound, one eastbound, and exhibited cluster cracking. Both Muskogee County (U.S. 69) and Rogers/Mayes County exhibited some cluster cracking. The report noted that some of the newer CRCP projects had a large number of closely spaced intersecting cracks that might lead to formation of punchouts [18].

1991 Six-State Field Investigation of CRCP

In the fall of 1991, Tayabji et al performed a pooled fund investigation of 23 CRCP sites in six states, including five sites in Oklahoma [9, 19]. The study included visual condition surveys, profile measurements, and FWD and corrosion testing of 305-m (1000-foot) test sections. Concrete cores were tested for strength, stiffness, and coefficient of thermal expansion. Base, subbase, and subgrade samples were collected and analyzed. The findings are summarized for each Oklahoma site as follows:

- **OK-1: Okfuskee County, I-40 Westbound**, completed in 1986, was designed as 229 mm (9 in) CRCP over 102 mm (4 in) CABB and a clayey sand subgrade, with tied PCC shoulders, 0.5 percent longitudinal steel, and 0.08 percent transverse steel. (Note: According to the 1991 ODOT and FHWA report cited above, this project was constructed with no transverse steel in the westbound direction.) The concrete was well graded and had average consolidation. The CABB was well graded and the subgrade was a clayey sand. Average crack spacing was 2.59 m (8.51 ft) and all cracks were medium severity with 19 percent "Y" cracks. The crack map of the test section reveals cluster cracking. A visual survey of 4.8 km (3 miles) of the project found the pavement was in generally good condition exhibiting only one PCC patch. Load transfer efficiency at cracks was variable. Average crack width was 0.63 mm (0.025 in). Depth of concrete cover over reinforcing ranged from 71 to 137 mm (2.8 to 5.4 in) and potential for steel corrosion was marginal. Average IRI was 837 mm/km (53 in/mi).

- **OK-2: Atoka County, U.S. 69 Northbound**, completed in 1988, was designed as 229 mm (9 in) CRCP over 76 mm (3 in) asphalt treated base and 305 mm (12 in) aggregate subbase, with tied PCC shoulders, 0.5 percent longitudinal steel, and 0.08 percent transverse steel. The concrete was well graded and had average consolidation. The asphalt treated base and the subbase were well graded, and the subgrade was a clay. Average crack spacing was 1.39 m (4.57 ft), 88 percent at medium severity, 12 percent at low severity, with 7 percent "Y" cracks. Cluster cracking was apparent within the test section. Average crack width was 0.48 mm (0.019 in). Depth of concrete cover over reinforcing ranged from 91 to 127 mm (3.6 to 5.0 in) and potential for steel corrosion was negligible.

- **OK-3: Logan County, I-35 Northbound**, completed in 1989, was designed as 254 mm (10 in) CRCP over a 76 mm (3 in) hot mix asphaltic concrete and an existing granular subbase, with tied PCC shoulders, 0.5 percent longitudinal steel, and 0.08 percent transverse steel, both epoxy-coated. The concrete was well graded and had poor consolidation. The asphaltic concrete base was well graded, and the subbase and subgrade were classified as A-4. Average crack spacing was 1.44 m (4.72 ft), 94 percent at medium severity, 6 percent at low severity, with 12 percent "Y" cracks. Cluster cracking was apparent within the test section. A visual survey of 6.4 km (4 miles) of the section found the pavement was in generally good condition exhibiting little distress. Average crack width was 0.54 mm (0.021

in). Depth of concrete cover over reinforcing ranged from 91 to 140 mm (3.6 to 5.5 in) and testing for potential for steel corrosion was not performed. Average IRI was 1169 mm/km (74 in/mi).

- **OK-4: Bryan County, U.S. 69 Southbound**, completed in 1985, was designed as a 229 mm (9 in) CRCP over a 152 mm (6 in) soil asphalt base, a 152 mm (6 in) select borrow subbase, and a clay subgrade. The design includes 0.5 percent longitudinal steel and 0.08 percent transverse steel, with tied PCC shoulders. The concrete was well graded and had average consolidation. The soil asphalt base and sandy subbase layer were uniformly graded, and the subgrade was a clay. Average crack spacing was 1.95 m (6.39 ft), 5 percent at high severity, 94 percent at medium severity, 1 percent at low severity, with 3 percent "Y" cracks. Within the test section, some cluster cracking and many crack spalls were apparent and one punchout was noted. Average crack width was 0.76 mm (0.030 in). Load transfer efficiency at cracks was highly variable. Depth of concrete cover over reinforcing ranged from 89 to 124 mm (3.5 to 4.9 in) and testing for potential for steel corrosion was not performed.

- **OK-5: Sequoyah County, I-40 Eastbound**, completed in 1991, was designed as a 254 mm (10 in) CRCP over a 102 mm (4 in) permeable cement-treated base and select borrow subgrade. The design includes 0.61 percent longitudinal steel and 0.08 percent transverse steel, with tied PCC shoulders. The concrete was well graded and had average consolidation. The permeable concrete base was uniformly graded and the subgrade was a clayey sand. Average crack spacing was 1.44 m (6.16 ft), 31 percent at medium severity, 69 percent at low severity, with 2 percent "Y" cracks. Cluster cracking or other distresses were not apparent within the test section. A visual survey of 6.4 km (4 miles) of the section found the pavement was in generally excellent condition exhibiting two PCC patches. Average crack width was 0.45 mm (0.018 in). Depth of concrete cover ranged from 86 to 163 mm (3.4 to 6.4 in) and potential for steel corrosion was negligible. Average IRI was 790 mm/km (50 in/mi).

Crack Spacing

When compared to the test sites in the other six states, the Oklahoma sites had the largest crack spacings (which the researchers attributed to smaller percentage steel) and lower load transfer efficiencies at cracks. The average crack spacing for all test sites was 1.34 m (4.40 ft), whereas the average crack spacing for the Oklahoma sites was 1.85 m (6.07 ft). Okfuskee County had the largest crack spacing of any site in the study, with an average of 2.59 m (8.51 ft). Okfuskee County also had the highest percent length of pavement with greater than 3 m (10 ft) crack spacing (indicating potential for crack spalls, steel rupture, and punchout) and the highest cluster ratio (explained below) of any site in the study. The researchers hypothesized that this cracking pattern is most likely due to the ambient temperature and curing conditions during construction. The average cluster ratio (a lower cluster ratio indicates less cluster cracking) for all the sites in the study was 0.29. The cluster ratio for the five Oklahoma sites ranged from 0.20 (Bryan County) to 0.85 (Okfuskee County), with average of 0.29 if Okfuskee County is excluded. In this study, the researchers related cluster cracking most to construction variability (i.e. depth of steel cover and concrete strength) and degree or quality of curing. The percentage of "Y" cracking was given for 15 of the test sections and averaged 11.9 percent. The Oklahoma sites varied from 2 to 19 percent "Y" cracking with an average of 8.6 percent.

Distresses

Visual distress surveys of sections within the study sites showed that the number of patches/punchouts per kilometer varied from none to 13.3 with an average of 6.0 (none to 21.4 per mile with an average of 3.7). The three Oklahoma sites which were surveyed for distresses (Okfuskee, Logan, and Sequoyah Counties), had an average of 0.25 punchouts/patches per kilometer (0.4 punchouts/patches per mile) within the surveyed sections. Bryan County had the lowest overall stiffness of total pavement system (including subgrade reaction) of any Oklahoma site.

Strategic Highway Research Program (SHRP) GPS-5 Data

The Tayabji study also presented a summary of the data collected to date for the SHRP GPS-5 (CRCP) sites across the country. The 85 CRCP projects being monitored include three Oklahoma sites in Washington, Pittsburg, and Mayes Counties. The average crack spacing for each of the three Oklahoma projects was 1.69, 1.57, and 1.20 m (5.56, 5.15, and 3.94 ft), respectively, while the average crack spacing for all GPS-5 projects was 1.28 m (4.20 ft). No distress data for the SHRP sites was available from the report [19].

1996 ODOT Field Division Survey

In June 1996 each of the ODOT field divisions was asked to perform a visual condition survey of the CRCP projects within that division. Field personnel recorded the number of punchouts and/or patches in each direction for each of 44 projects. The number of punchouts/patches per kilometer and per mile for each project are given in the last two columns of Table 1. A summary of the punchout/patches frequencies are shown below in Table 2. Half of the projects had no punchouts or patches and only four projects had more than 2 punchouts/patches per kilometer (3.2 per mile). One or fewer punchouts per kilometer (1.6 or fewer per mile) were found on 86% of the projects. The 44 projects had an overall average of 0.7 punchouts/patches per kilometer (1.1 punchouts/patches per mile). The four projects with the most distresses were Tulsa (I-244 at Denver Ave.), Bryan, Okfuskee, and Muskogee (near Warner). Contributing factors to the number of distresses on these four projects include age of the pavement (the Tulsa and Muskogee County projects are over 20 years old), base type (the Bryan County project was constructed with a soil asphalt base), and lack of transverse reinforcing (the Okfuskee County project lacks transverse reinforcing westbound and the Muskogee County project in both directions).

Table 2. Punchout/Patches Frequencies for 44 Projects.

Number of Punchouts or Patches/kilometer	Number of Projects	Percent of Projects
Nonc	22	50%
0.1 - 1.0	16	36%
1.1 - 2.0	2	5%
2.1 - 4.7	4	9%

1996 ODOT CRCP Tour

On July 31 and August 1, 1996 Mr. Tim Borg, ODOT Pavement Engineer, conducted a tour of selected Oklahoma CRCP projects. Participants included Mr. John Hallin of the FHWA, industry representatives, paving contractors, and ODOT personnel. The CRC pavements inspected ranged in age from newly constructed to over 25 years old. The oldest of these was constructed using 0.61 percent longitudinal steel, asphalt shoulders, and a fine aggregate bituminous base. Mr. Hallin considered this pavement to be in "excellent condition considering its age [20]." The CRC pavements constructed between 1985 and 1990 with 0.50 percent longitudinal steel had generally more distresses and longer crack spacings than newer pavements constructed in the 1990's with 0.61 percent longitudinal steel and a cement-treated base. Of concern, however, were the cracking patterns displayed in the 1990's pavement, with cluster, "Y", and diagonal cracking and long crack spacings present in some areas. Two of these eight projects had experienced a few punchouts. Mr. Hallin noted that other states have experienced problems with cement-treated bases bonding to the CRCP which gives the effect of a thicker and therefore under-reinforced slab. (An under-reinforced slab would have longer crack spacing with associated cluster cracking.) It was also observed that on several of the newer projects the longitudinal joint between the PCC shoulder and outside lane had not been sawed and sealed. This was accompanied by transverse cracks which turned 90 degrees and ran longitudinally for a short distance near the right shoulder. Sympathetic cracks had formed across the roadway at many of the transverse saw cut locations in the shoulders. Mr. Hallin recommended that ODOT increase the percentage longitudinal steel used and decrease the cement content of the cement-treated base. Other design recommendations included placing the longitudinal steel at one-third slab depth and widening the outside lane. Notes from this tour are included as Appendix B.

DISTRESS NORMS

Although CRCP has been used extensively by many states, information concerning typical or expected amounts of distress for varying ages of pavements and is not abundant. Classification of pavement condition according to number of distresses is also scarce. In 1981 Gutierrez de Velasco and McCullough categorized zero to three punchouts/patches per mile as "good," three to nine as "fair," and more than nine as "bad." They found that pavements were generally overlaid when punchouts/patches "reached a level of 20 per mile"[21]. LaCoursiere and Darter rated pavements as "poor" if there were more than five distresses per mile, "fair" if there were two to five distresses per mile, and "good" or better if there were less than two distresses per mile [22]. Using the average of these two rating systems, Oklahoma would have one CRCP project in the "poor" category, four in the "fair" category, and the 39 remaining would be considered "good."

Illinois

A 1978 study of Illinois CRC pavements summarized the total distresses (including punchouts, steel rupture, construction joint failure, construction related distress, and existing patches) for 1979 km (1230 miles) of CRCP Interstate projects ranging in age from 5 to 14 years [22]. Almost 80 percent of the total length of the projects had less than 1.2 distresses per kilometer (two distresses per mile). About 11 percent of the mileage had 3.1 or more distresses per kilometer (five distresses per mile) and were considered difficult and costly to keep in operation and in need of rehabilitation. Of the 132 projects, 11 percent displayed no distress, 12 percent experienced steel ruptures, and 45 percent had one or more edge punchouts. More than one-third of the projects had failed or patched construction joints.

Texas

A 1994 paper by Dossey and Hudson describes prediction models based on 20 years of historical condition survey data for CRCP across Texas. Data collected showed that the occurrence of severe punchouts requiring patching began when CRC pavements were about 5 years of age and increased linearly with age. Fifteen year old pavements had an average of about 0.8 severe punchouts, 1.1 asphalt patches, and 5 PCC patches per mile. After 15 years, more than half of the CRC pavements were overlaid. Significant factors influencing the number of punchouts/patches included swelling content of soil, coarse aggregate type, average annual minimum temperature, and average yearly rainfall [23].

TEXAS DOT CRCP DESIGN AND CONSTRUCTION PRACTICES

Mr. Gary Graham of the Texas Department of Transportation (TxDOT) Pavement Design Section was contacted by telephone about their CRCP design methods. Mr. Graham said that TxDOT uses the AASHTO Guide for Design of Pavement Structures to determine pavement thickness. TxDOT typically uses 25 to 50 mm (one to two inches) of hot-mix asphalt bond breaker over a 150 mm (6 in) cement-treated base. They construct full concrete shoulders and rarely use drainage systems with their CRCP. They experience some cluster cracking but he is not aware of any major problems caused by cluster cracking. When the pavement eventually does need rehabilitation, they have had good results from repairing punchouts then overlaying the CRCP with asphalt.

The experiences of TxDOT with CRCP are more fully described in a 1993 paper by Andrew J. Wimsatt [24]. Texas began using CRCP extensively in the 1950s and 1960s and it is used today more than any other concrete pavement type in Texas because it is virtually maintenance-free "if designed and constructed properly." Most of the districts are satisfied with the performance of CRCP except the Beaumont District which has encountered problems. Another factor which favors its use is the good performance of asphalt overlays on CRCP. In general, the transverse cracks in CRCP are narrow and do not reflect through a 100 to 150 mm (4 to 6 in) asphalt overlay.

The early designs of CRCP in Texas used either 0.5 or 0.6 percent steel with flexible paved shoulders. In rural areas, these early pavements had numerous punchouts which formed near the edge of the driving lane due to high edge stresses from truck traffic and lack of tied shoulders. For the past ten years, virtually all Texas CRC pavements have used tied shoulders (CRCP) and a longitudinal sawed joint (instead of a construction joint) between the shoulder and outside lane. Another problem identified by Texas researchers was the use of siliceous river gravel in the concrete mix which was found to result in close transverse crack spacing and earlier punchout formation than CRCP using limestone aggregate. This lead to the revision of several standards to address the use of siliceous river gravel.

Most of the early CRCP in Texas was built directly on cement stabilized subbases which tended to adhere to the concrete pavement, resulting in excessive cracking. Consequently, most districts now use 100 to 150 mm (4 to 6 in) asphalt stabilized subbases. Any cement stabilized subbases are required to have a bondbreaker. It is required that all concrete pavements use "non-erosive, dense graded, stabilized subbases, which are either asphalt-stabilized or cement-stabilized subbases. Lime-treated subgrade and flexible (or granular) bases have not been found to be an effective subbase for concrete pavements in Texas under high traffic areas."

The current TxDOT standard (see Appendix A, Figure 6) increases the percentage longitudinal steel with increasing pavement thickness. The percent longitudinal steel varies from 0.43 percent for 200 mm (8 in) pavements to 0.70 percent for 380 mm (15 in) pavements. In comparison, the current ODOT standard (CRPB 2-3) specifies 0.6 percent longitudinal steel for all pavement thicknesses. TxDOT also increases transverse steel with increasing pavement width in accordance with the design recommendations of the Concrete Reinforcing Steel Institute [6]. The percent transverse steel varies from 0.07 to 0.17 percent depending on the pavement width and spacing varies from 53 to 94 cm (21 to 37 inches). ODOT varies transverse steel from 0.06 to 0.09 percent by specifying the same bar size and spacing (112 cm or 44 in) for all pavement thicknesses and widths. A comparison of TxDOT and ODOT design reinforcing for comparable pavement thicknesses is shown below in Table 3.

Table 3. Comparison of TxDOT and ODOT Reinforcing in CRCP.

Pavement Thickness	State	Long. Bar Size	Long. Bar Spacing	% Longitud. Reinforcing	% Transv. Reinf. for width ≤ 40'(1)
200 mm (8")	ODOT	n/a	n/a	n/a	n/a
	TxDOT	#5	230 mm (9")	0.43	0.07
230 mm (9")	ODOT	#6	200 mm (8")	0.61	0.09
	TxDOT	#5	190 mm (7.5")	0.46	0.07
250 mm (10")	ODOT	#6	185 mm (7.25")	0.61	0.08
	TxDOT	#6	215 mm (8.5")	0.52	0.07
280 mm (11")	ODOT	#6	165 mm (6.5")	0.61	0.07
	TxDOT	#6	180 mm (7")	0.57	0.07
305 mm (12")	ODOT	#6	150 mm (6")	0.60	0.06
	TxDOT	#6	150 mm (6")	0.61	0.07
330 mm (13")	ODOT	n/a	n/a	n/a	n/a
	TxDOT	#6	265 mm (10.5")(2)	0.65	0.07
355 mm (14")	ODOT	n/a	n/a	n/a	n/a
	TxDOT	#6	240 mm (9.5")(2)	0.66	0.07
380 mm (15")	ODOT	n/a	n/a	n/a	n/a
	TxDOT	#6	215 mm (8.5")(2)	0.70	0.07

(1) TxDOT requires increased transverse steel for wider pavements.
(2) Two layers of steel are placed for pavements 330 mm (13") thick and greater.
n/a = not applicable (ODOT standards specify 230 to 305 mm (9" to 12") pavement thicknesses only).

CONCLUSIONS

Although a comprehensive distress survey including crack mapping has not been performed on all state CRCP projects, the data available from previous surveys by ODOT and others indicate overall good performance of the state's CRCP when compared to other states. The Tayabji study found fewer punchouts per kilometer for the Oklahoma sites (0.24 per km, 0.4 per mile) than the average for all sites in the study (2.2 per km, 3.7 per mi). The visual survey conducted by ODOT field divisions found 22 out of 44 projects had no punchouts or patches. The average for 44 Oklahoma CRCP sites was 0.7 punchouts per kilometer (1.1 per mi) with only four projects exhibiting a large number of punchouts/patches per kilometer. Of these four projects, two are over 20 years old, one was built with a soil asphalt base, and another without transverse steel in one direction.

In the Tayabji study the Oklahoma sites were found to have larger than average crack spacings which is thought to be a significant influence on long-term performance and, thus, on life-cycle costs [3, 25]. Tayabji considered the use of 0.5% longitudinal reinforcing to have contributed to the larger crack spacing. In comparing the amount of cluster cracking, the average of the cluster ratios (if Okfuskee County was excluded from the average) for the Oklahoma sites was the same as the average for all the sites in the Tayabji study. SHRP data for CRCP sites also showed that Oklahoma had larger crack spacings than the average but were still within design tolerances given by AASHTO. Mr. John Hallin of the FHWA concurred that Oklahoma's use of 0.50% longitudinal steel in the 1980s had resulted in pavements with less than satisfactory performance.

Investigation of the design and construction methods used by the TxDOT revealed a number of differences with ODOT practices. One of the most significant differences, in terms of the effect on cracking patterns, may be Texas' practice of using an asphalt bond breaker between the CRCP and cement-treated base. TxDOT uses full width CRCP (including shoulders) with a sawed longitudinal joint between the outside lane and shoulder while ODOT uses tied PCC shoulders. Texas increases the percentage of longitudinal steel with increasing thickness of pavement; ODOT maintains the same percentage longitudinal steel for all pavement thicknesses. TxDOT increases the percentage of transverse reinforcing for wider pavements as recommended by CRSI while ODOT actually decreases the percentage of transverse steel with thicker pavements. In addition, TxDOT varies the spacing of transverse reinforcing from 53 to 94 cm (21 to 37 in) while ODOT uses 112 cm (44 in) spacing.

RECOMMENDATIONS

The concern expressed by both Tayabji and Hallin regarding large crack spacings (and accompanying cluster cracking) due to low steel percentage has been lessened through ODOT's current use of 0.61 percent longitudinal steel. However, cracking patterns exhibited by newer pavements constructed with 0.61 percent steel are less than desirable and these projects warrant monitoring. Regular visual condition surveys of these pavements are needed to quantify levels of distress and enable ODOT to adequately evaluate the current CRCP design standard. ODOT should provide an asphalt bond breaker between the CRCP and the cement-treated base, as Texas does, or decrease the cement content of the base, as Mr. Hallin recommends. Longitudinal construction joints between the PCC shoulder and outside lane should be sawed and sealed on all future projects to prevent aberrant cracking near the shoulders. The Pavement Design Committee should evaluate Mr. Hallin's recommendations concerning increasing longitudinal steel to 0.65 to 0.70 percent and increasing outside lane width.

ODOT can continue to seek improvement in the performance of future CRC pavements through consideration of other factors such as ambient conditions during construction, depth of steel placement, swelling potential of soil, coarse aggregate type, and rate of strength gain [9, 23]. Detrimental early age cracks associated with hot weather placement can be minimized by restricting placement times or reducing temperature rise by precooling materials or using fly ash [10]. Consideration should be given to increasing longitudinal steel on projects with heavy traffic and anticipated higher steel stresses in order to provide desirable crack spacing and maintain load transfer at crack locations. The percent of transverse steel should be kept constant for varying thicknesses of pavements and should increase for wider pavements.

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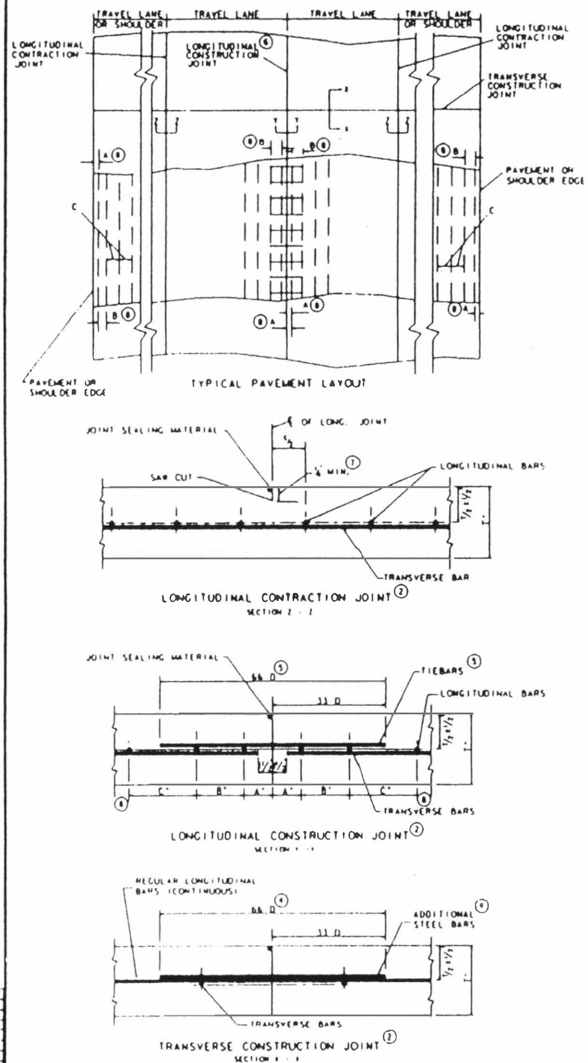
APPENDIX A
TEXAS DOT CRCP DESIGN STANDARD



T (IN.)	LONG. BAR SIZE	SPACING C (IN.)	TRANSVERSE STEEL REQUIREMENTS (3) FOR GIVEN PAVEMENT WIDTHS (FT)						
			≤ 40	41-50	51-60	61-70	71-80	81-90	91-100
8	5	9	#4 @ 36"	#4 @ 29"	#5 @ 37"	#5 @ 32"	#5 @ 28"	#6 @ 35"	#6 @ 32"
9	5	7.5	#4 @ 32"	#4 @ 26"	#5 @ 33"	#5 @ 28"	#6 @ 35"	#6 @ 31"	#6 @ 28"
10	6	8.5	#4 @ 29"	#5 @ 36"	#5 @ 30"	#6 @ 36"	#6 @ 32"	#6 @ 28"	#6 @ 25"
11	6	7	#4 @ 26"	#5 @ 32"	#5 @ 27"	#6 @ 33"	#6 @ 29"	#6 @ 26"	#6 @ 23"
12	6	6	#5 @ 37"	#5 @ 30"	#6 @ 35"	#6 @ 30"	#6 @ 26"	#6 @ 23"	#6 @ 21"
(2) 13	6	10.5	#4 @ 36"	#4 @ 35"	#4 @ 30"	#4 @ 25"	#5 @ 34"	#5 @ 31"	#5 @ 27"
(2) 14	6	9.5	#4 @ 36"	#4 @ 33"	#4 @ 27"	#5 @ 36"	#5 @ 32"	#5 @ 28"	#6 @ 36"
(2) 15	6	8.5	#4 @ 36"	#4 @ 31"	#4 @ 26"	#5 @ 34"	#5 @ 30"	#6 @ 38"	#6 @ 34"

FOOTNOTES:

(2) FOR PAVEMENTS 13" OR GREATER IN THICKNESS, TWO LAYERS OF LONGITUDINAL AND TRANSVERSE STEEL SHALL BE USED. WHEN THE "DOUBLE STRIKE-OFF" PROCEDURE IS NOT USED CHAIRS WILL BE REQUIRED TO SUPPORT BOTH LAYERS OF STEEL, AS SHOWN IN THE TABLE ABOVE. THE SPACINGS SHOWN FOR THESE THICKNESSES ARE FOR EACH LAYER.

(3) TRANSVERSE STEEL MUST BE INCREASED AS PAVEMENTS WIDEN. PAVEMENT WIDTH SHALL BE MEASURED AT RIGHT ANGLES TO THE CENTERLINE AND SHALL INCLUDE ALL MAINLANES, CONNECTORS, RAMPS AND CONCRETE SHOULDERS THAT ARE TIED TOGETHER. WHERE WIDTHS EXCEED 100', ADDITIONAL TRANSVERSE STEEL WILL BE REQUIRED, UNLESS A "FREE" (NON-REINFORCED) LONGITUDINAL JOINT IS SHOWN ELSEWHERE IN THE PLANS. WHERE THE CENTER MEDIAN IS TO BE PAVED WITH CRCP AND A MEDIAN BARRIER IS PROVIDED, THE "FREE" (NON-REINFORCED) LONGITUDINAL JOINT WILL BE PLACED UNDER THE BARRIER.

(4) ADDITIONAL STEEL AT THE TRANSVERSE CONSTRUCTION JOINTS SHALL BE BARS OF EQUAL DIAMETER, AND A SPACING OF DOUBLE THAT SPECIFIED FOR THE LONGITUDINAL STEEL OF THE GIVEN THICKNESS. THE LENGTH OF THE BARS SHALL BE 66 TIMES THE BAR DIAMETER ("D").

(5) TRANSVERSE TIEBARS AT THE LONGITUDINAL CONSTRUCTION JOINTS SHALL BE BARS OF EQUAL DIAMETER AND SPACING TO THOSE SPECIFIED FOR THE TRANSVERSE STEEL OF THE GIVEN THICKNESS. THE LENGTH OF THE BARS SHALL BE 66 TIMES THE BAR DIAMETER ("D").

(6) PAVEMENT WIDTHS IN EXCESS OF 16' SHALL BE PROVIDED WITH A LONGITUDINAL JOINT (SECTION Z-Z OR Y-Y). THESE JOINTS SHALL BE LOCATED WITHIN 6" OF THE LANE LINES UNLESS SHOWN ELSEWHERE ON THE PLANS.

(7) IF SILICEOUS GRAVEL IS USED AS A COARSE AGGREGATE, THE SAW CUT DEPTH FOR LONGITUDINAL CONTRACTION JOINTS SHALL BE T/3.

(8) THE NUMBER OF BARS REQUIRED FOR THE VARIOUS PLACEMENT WIDTHS (INDICATED IN THE TABLE) INCLUDES BARS AT "B" SPACING ON BOTH SIDES WITH AN OVERHANG "A".
"A" SPACING SHALL BE BETWEEN 3" AND 4".
"B" SPACING SHALL BE BETWEEN 3" AND 9".
THE TWO SPACINGS COMBINED ("A" AND "B"), LOCATED AT BOTH LONGITUDINAL EDGES OF THE CONCRETE PLACEMENT, SHALL PROVIDE FOR THE REMAINING SPACE AND STEEL LOCATION TO ROUND OUT THE PLACEMENT WIDTH.

GENERAL NOTES

1. NO EXPANSION JOINTS WILL BE USED EXCEPT AT STRUCTURE ENDS OR FIXED OBJECTS AS SHOWN ELSEWHERE IN THE PLANS.
2. LONGITUDINAL AND TRANSVERSE BARS SHALL BE DEFORMED STEEL CONFORMING TO ASTM A-615 OR ASTM A-616 (GRADE 60) AS NOTED IN THE STANDARD SPECIFICATIONS.
3. FOR FURTHER INFORMATION REGARDING THE PLACEMENT OF CONCRETE AND REINFORCEMENT, REFER TO THE GOVERNING SPECIFICATIONS FOR "CONCRETE PAVEMENT".
4. DETAILS AS TO PAVEMENT WIDTH, PAVEMENT THICKNESS AND THE CROWN CROSS-SLOPE SHALL BE AS SHOWN ELSEWHERE IN THE PLANS.
5. WITHIN ANY AREA BOUNDED BY TWO FEET OF PAVEMENT LENGTH MEASURED PARALLEL TO THE CENTERLINE AND TWELVE FEET OF PAVEMENT WIDTH MEASURED PERPENDICULAR TO THE PAVEMENT CENTERLINE, NOT OVER 33% OF THE REGULAR LONGITUDINAL STEEL SHALL BE SPLICED.
6. THE LONGITUDINAL STEEL SHALL BE PLACED AT THE VERTICAL SLAB CENTER WITH A TOLERANCE OF 1/2 INCH. TRANSVERSE STEEL SHALL BE PLACED DIRECTLY ABOVE OR BELOW THE LONGITUDINAL STEEL.
7. SPLICES SHALL BE A MINIMUM OF 33 TIMES THE NOMINAL STEEL DIAMETER ("D").
8. BARS THAT REQUIRE BENDING SHALL BE GRADE 40 STEEL CONFORMING TO REQUIREMENTS OF ASTM DESIGNATION A 615. SPACINGS FOR GRADE 40 STEEL SHALL BE 2/3 OF THAT SPECIFIED FOR GRADE 60 STEEL.
9. THE REGULAR LONGITUDINAL STEEL AT TRANSVERSE CONSTRUCTION JOINTS SHALL EXTEND A MINIMUM OF FOUR FEET ON EITHER SIDE OF THE JOINT.
10. VIBRATION WITH HAND-MANIPULATED MECHANICAL VIBRATORS WILL BE REQUIRED ADJACENT TO ALL TRANSVERSE CONSTRUCTION JOINTS.
11. THE CHAIRS USED TO SUPPORT THE STEEL SHALL BE OF SUFFICIENT STRUCTURAL QUALITY AND NUMBER TO HOLD THE STEEL MAT WITHIN THE PLACEMENT HEIGHT TOLERANCES. CHAIRS SHALL BE OF A TYPE APPROVED BY THE ENGINEER.
12. WITH THE APPROVAL OF THE ENGINEER, MULTIPLE PIECE TIEBARS (THREADED COUPLING OR OTHER ADEQUATE DEVICE) MAY BE USED TO FACILITATE CONSTRUCTION PROVIDED THE SYSTEM DEVELOPS A FORCE EQUAL TO 1-1/2 TIMES THE MINIMUM YIELD STRENGTH OF THE TIEBAR SHOWN. THE SPACING FOR THE SYSTEM SHALL BE LESS THAN OR EQUAL TO THAT OF THE TIEBARS SHOWN.
13. JOINT, GROOVE AND SEAL DETAILS SHALL BE AS SHOWN ELSEWHERE IN THE PLANS.
14. LONGITUDINAL AND TRANSVERSE STEEL SPACING SHALL NOT VARY MORE THAN ONE-TWELFTH OF THE SPACING SHOWN HEREON.
15. IF WIDTHS OCCUR THAT ARE OTHER THAN THE TYPICAL WIDTHS SHOWN, INDIVIDUAL BARS OF THE SIZE SPECIFIED HEREON MAY BE ADDED OR REMOVED TO OBTAIN THE APPROPRIATE WIDTH. SPACING REQUIREMENTS SHALL NOT BE EXCEEDED, HOWEVER.
16. WHEN MACHINE-PLACING OF STEEL REINFORCEMENT IS USED, THE USE OF CHAIRS SHALL NOT BE REQUIRED, AND THE TRANSVERSE STEEL MAY BE PLACED ABOVE OR BELOW THE LONGITUDINAL STEEL.

CHAIR SIZES (in.) (2) FOR TWO LAYER STEEL PLACEMENT		
T (in.)	TOP STEEL	BOTTOM STEEL
13	6.5	3
14	7.5	4
15	8	4.5

SPACING C (in.)	NUMBER OF BARS (8) REQUIRED FOR VARIOUS TYPICAL PLACEMENT WIDTHS (ft.)						
	12	16	22	24	27	34	38
6	24	32	44	48	54	68	76
7	21	27	38	41	46	58	65
7.5	19	26	35	38	43	54	61
8.5	17	23	31	34	38	48	54
9	16	21	29	32	36	45	51
9.5	15	20	28	30	34	43	48
10.5	14	18	25	27	31	39	43

STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

CONCRETE PAVEMENT DETAILS

CONTINUOUSLY REINFORCED STEEL BARS

CRCP (B) - 89C

TEXAS

Figure 6

APPENDIX B
NOTES FROM ODOT CRCP TOUR

Oklahoma Department of Transportation
Research, Development & Technology Transfer

Date August 7, 1996

To David Ooten

From Ginger McGovern

Subject Tour of Oklahoma CRCP Sites
Item 2120-95-07

On Wednesday, July 31st and Thursday, August 1st, I participated in a tour of selected Oklahoma CRCP sites organized by Mr. Tim Borg, ODOT Pavement Design Engineer. The purpose of the tour was to obtain opinions about the performance of CRCP in Oklahoma. Attending were:

John Hallin, FHWA	Jack Telford, Materials Division
John Stites, FHWA	Tim Borg, Roadway Design Division
Jim Duit, Duit Construction	Kevin Bloss, Maintenance Division
Ray Collins, Koss Construction	Ginger McGovern, Research
Frank Cunningham, ACPA	

Following is a summary of observations at each CRCP project location:

Projects using 0.61% longitudinal reinforcing:

- Muskogee County, SAP-51(392) (completed in 1996) - Observed long crack spacing (sympathetic at shoulder joints and very few in between) on this pavement which has only been open about three months.

- Muskogee County, STP-51B(360) (completed in 1996) - Very few visible cracks in this project which was constructed in November and December 1995. Shoulders were poured directly against mainline with no sawed and sealed joint.

- Pittsburg County, DPIY-204(001) (completed 1994) - Southbound, observed variable crack spacing (from 4 to 8 ft) with some spalling. Some of the barrier wall segments are cracked also. No bond breaker is used between the OGPC bases and CRCP.

- Muskogee County, STP-404(66) (completed 1993) - Observed many diagonal cracks, no punchouts or patches; some cracks did a 90° turn and ran parallel to direction of traffic for a short distance near right shoulder; shoulders poured against mainline with no joint sealant. John Hallin said ODOT should probably use a wax-based curing compounds if we are going to pour shoulder right against CRCP.

- Pittsburg County, MAF-186(180) (completed 1993) - Southbound, observed fairly long crack spacing (about 8 ft) and associated cluster cracking; typically one crack at each shoulder joint and one halfway between; some longitudinal cracks in wheel paths; some crack spalling and a large popout. John Hallin said that Illinois noticed longer crack spacing on

CRCP with a cement-treated base. They theorize that the base bonds to the CRCP and gives the effect of a thicker slab which would, consequently, be under-reinforced. Jack Telford mentioned that two different sources of aggregate were used on different parts of this job. Northbound crack pattern looked very different from southbound. Cracks were closer (about 4 ft) with no observed longitudinal cracks and less cluster cracking.

- **Sequoyah County, IR-40-6(220)** (completed 1991) - Eastbound, observed sympathetic cracking with shoulder joints, good crack spacing overall. Westbound, observed some patches, some cracks going from shoulder joint to shoulder joint across entire roadway, edgedrains functioning, and fewer cracks than eastbound; cracks are difficult to see due to deep tining; constructed in the months of November and December.

- **Pittsburg County, MAF-186(185)** (completed 1991) - Southbound, observed sections of meandering cracks, some spalling, and "Y" cracks, with approximately 4 ft crack spacing. Edge joints were sawed and sealed.

- **Pittsburg County, F-186(183)** (completed 1991) - Southbound, observed irregular crack spacing, spalling, some "Y" and cluster cracks with long intervals in between. All four of the Pittsburg County U.S. 69 projects have heavy truck traffic (Tim Borg said 28%, but it seemed possible it could be even more).

- **Atoka County, F-299(99)** (completed 1990) - Southbound, observed shorter crack spacing than the other Atoka County projects and cracks were narrower and not as spalled.

- **Pontotoc County, MAF-235(009)** (completed 1990) - Contrary to the distress survey done by the field division, I observed no punchouts on this half mile long project. However, there appeared to be many distresses along the centerline caused by a milling machine used to place pavement markers.

- **Muskogee County, I-40-6(86)** (completed in 1973) - Eastbound, observed "Y" cracking, some cluster cracking (less than Okfuskee County), and many punchouts/patches; has a more regular and closer crack spacing than Okfuskee County; foundation failure in one area with lots of edge punchouts; a long stretch with no punchouts or patches; the right lane had settled in the failed section. Mr. Hallin called this spacing "pretty good" and said some of the cracks appeared construction related rather than structural. He also noted the typical section was a "bathtub" design. Westbound, many asphalt and PCC patches; ready for rehabilitation.

Projects using 0.50% longitudinal reinforcing:

- Muskogee County, MABRF-593(241) (completed 1990) - Observed "island cracks" (two cracks that joined at either end to form an island in the middle), cluster and "Y" cracking, some spalling of cracks, some sections with long crack spacing (about 20 ft) and associated cluster cracking. John Hallin rcferred to this as a "classic low percentage steel" cracking pattern and said he expects punchouts to develop in these areas. He also proposed eliminating the sawed transverse joints in the shoulder and just letting the cracks form where they may.

- Atoka County, F-299(45) (completed 1988) - Southbound, observed cluster and "Y" cracking with long spacing in bctween and moderate to scvere spalling. Reinforcing was tube-fed on this project.

- Atoka County, F-299(35) (completcd 1988) - Southbound, observed long crack spacing (about 10 ft); widc, spalled cracks; somc clustcr cracking but not as much as I would expect with such long crack spacing. Crack spacing improved and cracks were not as wide in section near the correctional facility. Construction was during hot weather and reinforcing placed with chairs. John Hallin thought this would be a good pavement if it had another 0.10% longitudinal steel.

- Sequoyah County, IR-40-6(222) (complcted 1989) - Crack spacing appeared normal; constructcd in latc fall and carly wintcr.

- Okfuskee County, IR-40-5(169) (completcd in 1986) - Eastbound, observed "sympathetic" cracks which occur at almost cvcry shoulder joint, close cracks (6 to 9 in) with concrete rubblizcd between, "Y" cracks, long crack spacing (10 to 15 ft) followed by a few cracks close together, longitudinal joint sealant has debonded between inside shoulder and lane, some edge punchouts; reinforcing steel on this job was tube-fed and it was constructed during hot weather. Westbound, observcd same sympathctic cracks, close cracks with rubblizing, long crack spacing with cluster cracks, many patches, east end of project worse than west end; base material was wet; shoulders were paved a week after mainline; Mr. Hallin called this "awful crack spacing" but was not conccrncd about the lack of transverse steel in the westbound direction.