ASSESSMENT OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT DESIGN AND BEHAVIOR IN OKLAHOMA

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ASSESSMENT OF CONTINUOUSLY REINFORCED

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APPROXIMATE CONVERSION FACTORS

From Metric(SI) units to English(US) units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.0394	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yds
km	kilometers	0.6214	miles	mi
		AREA		
mm^2	square millimeters	0.00155	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectares	2.471	acres	ac
km^2	square kilometers	0.3861	square miles	mi^2
		VOLUME		
mL	milliliters	0.0338	fluid ounces	fl oz
L	liters	0.2642	gallon	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
		MASS		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)		
^{o}C	degrees Celsius	$9/5(^{o}C)+32$	degrees Fahrenheit	^{o}F
		FORCE and STRESS		
N	newtons	0.224	pound-force	lbf
kPa	kilopascal	0.145	pound-force per square inch	lbf/in^2

CHAPTER 1

INTRODUCTION AND BACKGROUND

Introduction

The Oklahoma Department of Transportation has used Continuously Reinforced Concrete Pavements for sections of the state's heavily trafficked highways and roads. A large number of variables, such as the amount of reinforcing, the properties of concrete, subgrade, and base, construction practices, and environmental factors such as temperature and humidity, affect the performance of these pavements. In order to improve the performance of future pavements, an assessment of the performance of past projects needs to be made. This assessment is to identify problems, review current design, specification, and construction techniques of the projects.

The objective of this research is to identify the problems that have occurred and respond to the issues of design, construction and repair that will promote future successful performance of Continuously Reinforced Concrete Pavements (CRCPs) in Oklahoma. To accomplish this, a field observation of all existing CRCPs in Oklahoma was conducted to determine the performance of and problem areas with these pavements. The design procedures were reviewed.

The results of these efforts should provide the Oklahoma Department of Transportation with background data to help improve the current design, construction and repair practices of CRCPs.

Background

The *geometric design* of highways and roads focuses on vertical and horizontal alignments of the roadway, taking into consideration the speed and other factors of the expected traffic. The *structural design* of highways and roads focuses on the choice of paving materials and the pavement's resistance to environmental and traffic forces. The structural design of a pavement includes selection of materials for the base and subbase of the pavement and the material to use as surface course. These materials are selected to provide an adequate level of serviceability within the design life when subjected to axle loads of expected traffic and the environmental forces in the locality. Based on economic viability, ease of construction, composition and volume of traffic, environmental stresses and internal forces within the roadway, the pavement designer may select either a rigid or a flexible pavement.

Flexible pavements are surfaced with bituminous materials such as asphalt or unsurfaced aggregate pavements. Compared to rigid pavements, flexible pavements offer advantages such as lower construction and repair costs. However, because of the inherent weaknesses of the materials, flexible pavements generally do not provide adequate service for high volume roadways with higher percentages of heavy truck traffic such as those obtained on interstate highways.

Rigid pavements are built with Portland Cement Concrete (PCC). These pavements have a relatively higher capacity to withstand vehicular and environmental loads. A rigid pavement may be one of two types of PCC pavements: a Jointed Concrete Pavement (JCP) or a Continuously Reinforced Concrete Pavement (CRCP).

A JCP relies on regularly spaced joints to control cracking in the concrete. A CRCP has no transverse joints except at the beginning and end of the pavement and at interrupting structures like bridges. CRCPs use longitudinal steel reinforcement rather than transverse joints to control cracking. Transverse construction joints do occur at the end of each day's construction. However, in CRCP, the longitudinal reinforcing is continuous at these construction joints.

A rigid pavement will undergo deformation due to the loading imposed on it from the axles of vehicular traffic. The weight on each axle and the frequency of passes affect the life span of the pavement. The loading from environmental factors, such as temperature change or excessive moisture increase in the base and subbase, can also put a pavement at risk. Deformation in a rigid pavement also occurs because of shrinkage in concrete during hardening and drying. The volumetric change in concrete is restrained by friction between concrete and the base material resulting in increased stress in the pavement's surface course. The stress increase can lead rigid concrete to crack. If uncontrolled, cracking greatly limits the life of rigid pavements.

In JCP, the spaced joints are added to relieve concrete stresses, thereby controlling the cracks that develop in the concrete. For a project, depending on temperature, moisture changes and soil-pavement interaction, the distance at which joints are spaced is selected so as to prevent cracks forming between joints. The joints are sealed with flexible materials to protect the subgrade and base from moisture. If joints performed perfectly, then JCPs would be an excellent solution for high volume roads. However, the perfect joint does not exist. The problem associated with the use of JCPs is that the joints become points of structural weakness and early pavement failure. Moisture may get to the subbase through the joints and, if not drained quickly, can lead to weakening of the subbase and pumping. The edges of joints are locations for higher vehicular impact stresses. These stresses may cause faulting and spalling. If the joint sealant fails, the joints can become clogged with incompressible materials. When the clogged joint tries to close, the increase in stresses may result in crushing of the pavement. Because of these problems, a high level of joint maintenance is required and this translates into additional expenditure in finance and administrative time.

Attempts to eliminate the problems at joints and still control the cracks developed by stresses in concrete led to experiments with CRCPs. The regularly spaced transverse joints are eliminated in CRCPs. The size and spacing of cracks in the concrete are controlled with continuous longitudinal reinforcement. The longitudinal steel is proportioned to satisfy limiting criteria for *crack spacing*, *crack width*, and reinforcing *steel stress*. The limiting crack spacing is to check that the cracks are not so close together that localized failures or punchouts occur. The limiting crack width is to check the inflow of water and incompressible materials that can enter the crack and cause buckling or crushing. The limiting steel stress is to guard against failure of the steel reinforcement. If designed and constructed properly, CRCP can successfully provide resistance to applied loads with a minimum of maintenance and give the user a smooth ride during the analysis period (design life) of the pavement which, for CRCPs is typically 20 to50 years.

The successes of the first attempts with CRCPs by the U.S. Bureau of Public Roads on the Columbia Pike near Washington D.C. (1921), U.S. 40 at Stilesville, Indiana (1939), the Vandalia experiment on U.S. 40 at Vandalia, Illinois (1947), and Route 130 near Highstown, New Jersey (1949), paved the way for design, construction and management based on the experience gained [Ref. 7]. With the removal of transverse joints from these CRCPs, the problems with transverse joints were removed. However, because of the continuity for long distances, CRCPs created problems unique to their type of construction. There were large relative movements at the ends of the pavements requiring special consideration, and there was the problem of punchouts in the pavements. Another observation is the irregular spaced transverse cracks and other crack patterns. The crack pattern, though not a functional problem, can be disconcerting to those inexperienced with CRCPs.

Various state Departments of Transportation in the United States have worked diligently to determine appropriate relationship between traffic and environmental conditions on the design thickness and reinforcement of CRCPs [Ref. 4, 5, 8, 11, 16]. There have been other studies done in Oklahoma and elsewhere to determine the response of CRCP to vehicular and other stresses [Ref. 10, 14]. These have resulted in better design, construction, and management of reinforcement of CRCPs.

Continuously Reinforced Concrete pavements have been used on some major highways in the United States. The U.S. is currently one of the leading users of CRCPs, and there are several other users worldwide.

In the *United Kingdom* CRCP has been used on part of the M62 Trans-Pennine motorway linking Liverpool and Hull. The Mercer and Bullet review [Ref. 12] of design, construction and maintenance of concrete pavements in the United Kingdom since 1969 reveals that when designs presented by bidders in unreinforced concrete and reinforced concrete were compared, the unreinforced concrete pavement design/construction packages were about twelve percent cheaper than those for reinforced concrete. Because of the anticipated savings with the design and construction, doweled unreinforced concrete pavements were more often the choice for construction. However, critical review of maintenance costs reveals the greater benefits of the longer service life of CRCP design. The advantages of CRCP were found to include better load-carrying characteristics, no joints to construct or maintain, suitability for use in areas subject to settlement and the ease of overlaying initially or later to add strength. The study reports that CRCP is being used for some of the heavily trafficked roads in United Kingdom although they cost about twenty percent more than unreinforced concrete. The study also mentioned the advantage in using high-strength concrete to reduce early cracking tendencies, surface wear and joint spalling. By using thinner slabs, the costs were found to be comparable to those of United Kingdom's normal strength pavements. When CRCP has been used as an overlay to repair existing flexible roads, the construction and costs are shown to be comparable with black top overlays.

In *Asia*, the 850 km North-South Expressway of the Malaysian mainland begins from the Thailand border in the north to the Singapore causeway in the south. Construction was completed in 1994 [Ref. 19]. The Expressway has about 150 km of CRCP. The CRCP required 40,000 metric tonnes of high-tensile steel bars, 65,000 m^3 of grade C40 concrete, 250,000 metric tonnes of portland cement and 1,200,000 metric tonnes of coarse and fine aggregates. Three years after construction, the CRCP was reported to require minimal maintenance. The design used UK Department of Transportation Standards HD14/87.

CRCPs have been used extensively in *Belgium*. In 1973 a section of Highway 411 was constructed with 200 mm CRCP. Construction with CRCP was repeated for another section of Highway 411 in 1978, two more sections in 1978, a section in 1987 and another in 1988 [Ref. 20]. Still in Belgium, 200 mm CRCP on 150 mm cement-treated base was constructed on a section of Highway 4 in 1979 and some more in 1983.

Highway 97, also in Belgium, has had three projects executed using 200 mm CRCP with cement-treated base in 1975, 1984, and 1985. The CRCP sections were reported to have performed better than the JPCP sections.

Additional examples include the construction of a CRCP as part of the Malmo-Angelholm motorway at Lottinge, near Stockholm, financed in 1964 by the *Swedish* Technical Research Council [Ref. 17], and in *Australia*, part of the Lapstone Extension to M4 Motorway in Sydney was constructed with CRCP [Ref. 7].

The use of CRCP in Oklahoma started in 1969. The first projects were on interstate highway I-35 which has a very high truck traffic volume. Two of the projects of lengths 11.511 km and 10.497 km are in Carter County and a third project of length 10.307 km is in Murray County. There is a 0.122 km section of the high traffic interstate highway I-244 in Tulsa County also constructed in 1969 using CRCP. The use of CRCP continued until 1972, and up to that time, 180 lane-kilometers had been laid. It was twelve years before construction of CRCP resumed in 1984. By 1989, there was about 280 lane-kilometers of new CRCP laid. By 1991, there was total statewide of more than 760 lane-kilometers in various counties across the state. Oklahoma had about 1200 lane-kilometers of CRCP by the end of 1997. Figure 1 gives a pictorial view of the length of CRCP constructed in the state.

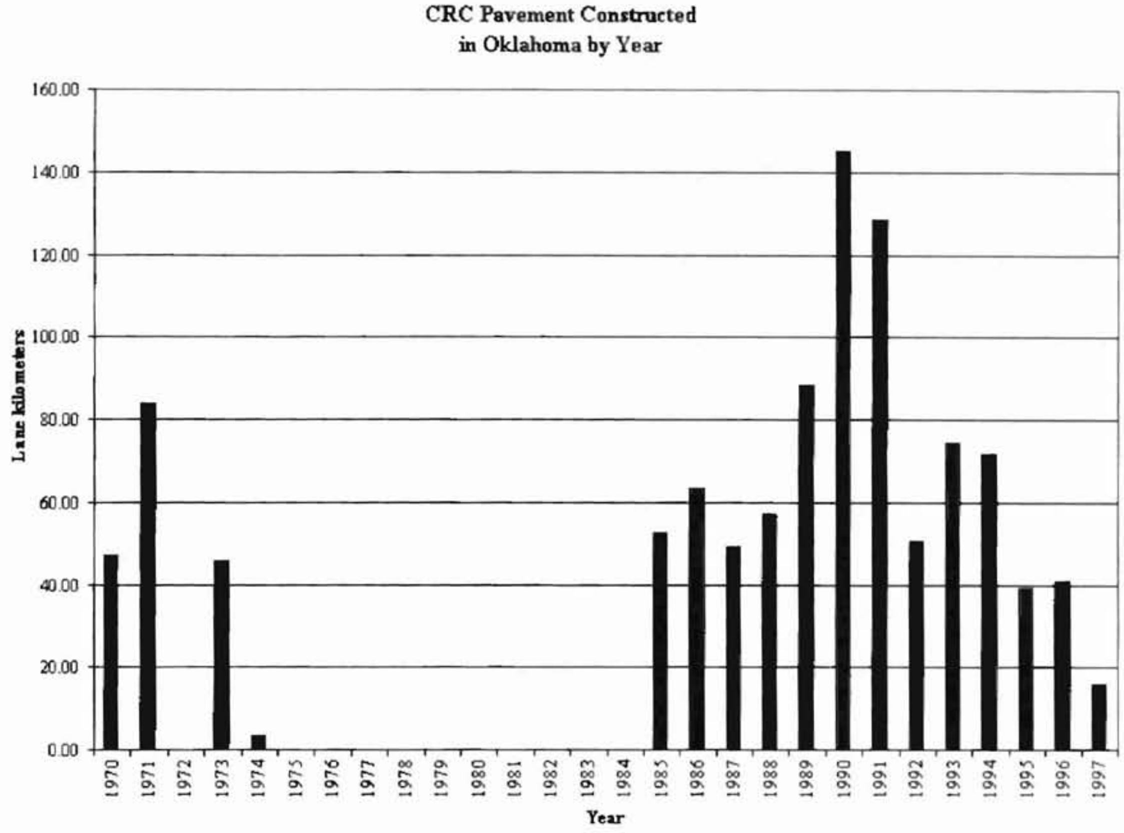

Figure 1. Continuously Reinforced Concrete Pavement Construction in Oklahoma

In Oklahoma, CRCPs have been used predominantly on interstate highways I-35, I-40, and I-244 and on heavily traveled U.S. highway systems US 69, US 75, and US 412. There are some examples of CRCPs on lower volume roads. One such example is the 0.764 kilometer section of the four lane divided state highway SH 3W in Pontotoc County was constructed in CRCP in 1990. There is also the 3.91 km stretch constructed as part of Rogers Lane in Comanche County. In the same period, three road projects of 1.260-kilometer, 8.080-kilometer and 3.627-kilometer lengths were completed at sections of the Lake Hefner Parkway (SH 74) using CRCP. Lake Hefner Parkway is a divided urban highway with three lanes in each direction at some sections. During this period, Oklahoma Department of Transportation has conducted studies to improve the understanding of CRCP and the performance of the terminal end joints which need careful attention during construction [Ref. 15].

ODOT has recognized the effectiveness of CRCP as a surface course for high volume roads and is committed to continuing the construction of CRCPs. The following report will assess the performance and current practices in design of CRCPs in Oklahoma to help ODOT improve the performance of CRCPs in the state.

CHAPTER 2

DESIGN OF CRCPs IN OKLAHOMA

Introduction

This chapter will focus on the American Association of State Highway and Transportation Officials (AASHTO) rigid pavement design formulas and calculations that lead to the required slab thickness and amount of reinforcement in a CRCP for a given loading, material properties and environmental conditions. The parameters that affect slab thickness and amount of reinforcing will be explained. Suggestions on improving the design process in Oklahoma will be made where necessary.

Design Methods Used in Oklahoma

The 1992 Oklahoma Department of Transportation Roadway Design Manual recommended two methods for pavement design. The two methods were the Oklahoma Subgrade Index (OSI) method and the AASHTO method found in the AASHTO Guide for design of Pavement Structures [Ref. 1]. Current ODOT procedures recommend the AASHTO method for design.

1. Oklahoma Subgrade Index (OSI) Method

Oklahoma Subgrade Index (OSI) method was developed by ODOT in the early 1960's for design of flexible pavements [Ref. 11]. An OSI number is deduced from the subgrade's liquid limit, plasticity index, and the percentage of fines passing #200 sieve. An empirical relationship considers other influences on the design, such as functional classification of the highway, design wheel load, shoulder factor and a climate factor. These are related through equations and nomographs to establish the required slab thickness.

Concrete slab thickness design

For rigid pavements, slab thickness is based on policy more than on calculations. In other words, traffic input data and soil investigation data are not used. The wording of the manual states, "The OSI rigid pavement design policy is as follows:

1. Minor collectors should have 9 inches (225 mm) of dowel-jointed Portland Cement Concrete (PCC).
2. Major Collectors should have 9 inches (225 mm) of continuously reinforced concrete pavement (CRCP) or 10 inches (250 mm) of dowel-jointed PCC.
3. High-type facilities (e.g., freeways, principal arterials) always have 10 inches (250 mm) of CRCP.
4. Every rigid pavement design is placed on 4 inch, non-erodable base. Shoulders should be plain PCC pavement tied to the travel lane. Plastic soils with the potential to swell and shrink (PI>25) should be stabilized or undercut and replaced."

Reinforcement Design

In 1969 and early 1970s longitudinal reinforcement specified for the concrete surfacing in projects designed with the OSI method was typically 0.61% of total slab area. Most of these pavements are in municipal areas of Tulsa County. Some pavements constructed in the early eighties have 0.50% longitudinal steel.

Highways designed using this policy include the 8.9 km IR-35-4(111)192 on highway I-35 in Noble County. This was designed in 1988. The final recommendation was for 250 mm CRC surfacing on 100 mm lean concrete base with 300 mm treated 14% fly ash. The design traffic data for the project was:

Wheel load	15000	% Heavy Comm. Traffic	25
ADT (Present-1988)	10500	Overloaded Axles/100	15
ADT (Future-2008)	20000	Traffic Factor	338
ADT (Average)	15000	E.B.T. Adjustment	+7
OSI	28		

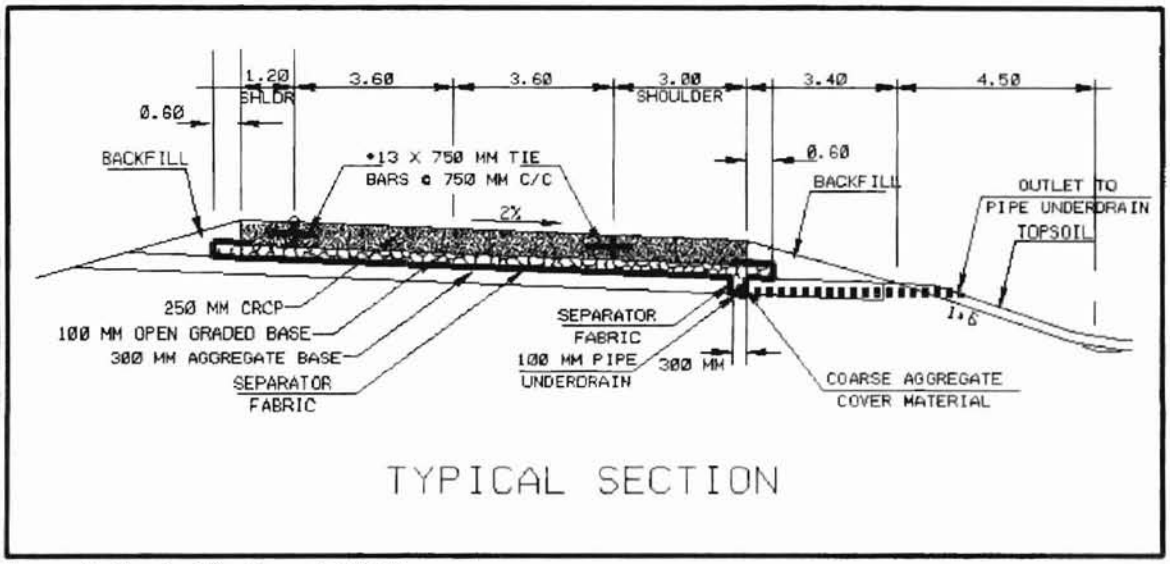

Figure 2. Typical Section of CRCP

2. AASHTO Method

There are two requirements in the design of the concrete surfacing of CRCPs. These are the concrete slab thickness and the amount of reinforcing steel. The AASHTO Guide gives equations for the determination of these quantities. According to the AASHTO Guide, the equation for determining pavement thickness "was derived from empirical information obtained at the AASHO Road Test. As such, these equations represent the best fit to observations at the Road Test" [AASHTO Guide, 1993]. There is one equation for determining concrete slab thickness. Longitudinal Reinforcement design is controlled by crack spacing, crack width, and steel stress. Three equations are given in the AASHTO Guide for the design of longitudinal reinforcement.

The equations for design are as follows:

Concrete slab thickness design

$$\log w_{18} = Z_R S_O + 7.35\log(h+1) - 0.06 + \frac{\log\left(\frac{\Delta PSI}{4.5-1.5}\right)}{1+\frac{1.624*10^{7}}{(h+1)^{8.46}}} + (4.22 - 0.32p_t)\log\left(\frac{S'_c * C_d\left(h^{0.75} - 1.132\right)}{215.63J\left(h^{0.75} - \frac{18.42}{(E_c/k)^{0.25}}\right)}\right) \qquad \ldots\ldots\ldots\ldots \quad 1$$

where

h = the overall thickness of concrete, (inches)

w_{18}= estimated number of 18 kip equivalent single axle loads (ESALs) in the design lane for the performance period. For any axle, the ESAL is a number that represents a damaging effect of the axle expressed in terms of the damaging effect of an 18-kip single axle load.

AASHTO has details on converting mixed traffic to ESALs in Appendix D of the AASHTO Guide [Ref. 1]. The traffic data used in the equation are axle load, axle configuration, and number of applications.

ODOT uses an ESAL factor of 4.066 times the design traffic of 5+ Axle Tractor Semi-Trailer obtained in the traffic count for rigid pavement design. All other traffic is neglected.

$w_{18}=D_D*D_L*\hat{w}_{18}$ [Ref. 1]. $\qquad \ldots\ldots\ldots\ldots \quad 2$

D_D= directional distribution factor (ratio by weight of traffic)

D_L= lane distribution factor (ratio by volume of traffic) when two or more lanes are available in one direction

$\hat{w}_{18}$= cumulative two-directional 18 kip ESAL units predicted for a specific section of highway during the analysis period.

$$\hat{w}_{18} = w_{1year}\left[\frac{(1+g)^{Y}-1}{g}\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 3$$

w_{1year} = estimated two- directional 18 kip ESAL applications during the first year of the pavement's life

g= projected growth rate of traffic

The growth rate(s) assumed in the estimation of future traffic is very important. Project Number STP-11B(334) in Division 1 was constructed in 1995. The file date in the Design File Data is 1993 at which time the %T3 was 4%. At end of construction the 1995 %T3 had already reached 15%. The predicted ESALs using the 15% was about double what was used in the design. If the 15% T3 traffic is maintained then this project will be a case of underdesign pavement and the CRCP will not last the design life planned for the highway.

Z_R = standard normal deviate obtained from the reliability design factor F_R by the equation:

$Z_R = (-\log F_R)/S_O$ [Ref. , Part I 4.2.3 and Part I Table 4.1.]

This factor is like the Importance Factor in bridge design and relates to the level of risk assumed to avoid traffic interruption during the service life of the pavement. The AASHTO Guide gives Suggested Levels of Reliability for Various Functional Classifications in Table 2.2. ODOT typically uses 90%. For a heavily trafficked highway as interstate I-35 between Oklahoma City and Texas, any lane closures for repair has a very high cost to users. For a facility of that level of usage, a reliability level of about 97 % or better will lead to a reinforced concrete slab thickness greater than that obtained for a 90% reliability level. A local road in Choctaw, which is not heavily trafficked and where lane closures for repair does not involve a high user cost, may use a reliability of 50 to 80 % and this will lead to a thinner pavement structure.

S_o = combined standard error of the traffic prediction and performance prediction [Ref. 1, Part II 2.1.3 and 4.3]. It ranges from 0.30 to 0.40. For a given project, if the state has a Measuring Site near or within that project location, and has extensive data in traffic counts and weigh-in-motion, then a good projected future 18-kip ESAL traffic estimate can be obtained, taking other economic developments into account in the the estimation. For a highly reliable estimate the value of S_o may be as high as 0.39. If, on the other hand, the projected future 18-kip ESAL traffic estimate cannot be made accurately due to inadequate traffic data and performance variables, then a low value of S_o, say 0.32, may be used.

The AASHTO Guide states that "by treating design uncertainty as a separate factor, the designer should no longer use 'conservative' estimates for all the other design input requirements. Rather than conservative values, the designer should use his best estimate of the mean or average value for each input value. The selected level of reliability and overall standard deviation will account for the combined effect of the variation of all the design variables."

ΔPSI =design serviceability loss = p_i-p_t [Ref. 1]

p_i = initial design serviceability index

p_t = terminal design serviceability index

The serviceability index grades the pavement's performance on a scale of 0 to 5. For any type of pavement, whether rigid, flexible or aggregate-surfaced roads, the best performance level is given an index of 5, and the worst level (impossible road) is assigned an index of 0. The design serviceability loss, ΔPSI, is the change in the pavement's performance that will warrant construction work to be done on the roadway.

The terminal serviceability index, p_t, of 2.5 or higher for major highways and 2.0 or higher for low volume roads are suggested values to use in design. The initial serviceability index, p_i, of 4.5 is used for rigid pavements.

E_c = concrete elastic modulus, [Ref. 1] , psi,

AASHTO accepts the following relationship given in the ACI 318-95,

$Ec = w_c^{1.5}(fc')^{0.5}$

$90\ lb/ft^3 < w_c < 155\ lb/ft^3$,

where w_c is the unit weight of concrete, in lb/ft^3, and fc' is the PCC compressive strength (psi) as determined by AASHTO T 22 T 140 [Ref. 2], or ASTM C 39.

S'_c = concrete modulus of rupture,

The modulus of rupture (flexural strength) is an average 28-day flexural strength obtained from flexural beam tests using simple beams with third point loading as specified by AASHTO T 97 [Ref. 2], or ASTM C 78. ODOT has stopped doing the flexural beam tests but still does compression tests on cylinders.

C_d = drainage coefficient, [Ref. 1]. This factor is not related to the runoff from the surface of the highway nor the side ditches along the highway. The factor is related to and accounts for the ability of the pavement structure to rid itself of water under the surface course within a specified period. The greater the chances that the base, subbase and subgrade will remain wet for long periods, the weaker the foundation of the pavement and the smaller the value of C_d that may be selected for design. Table 2.5 of the AASHTO Guide gives recommended values of C_d for rigid pavements. The value ranges from 1.25 for pavement foundations that drain in 2 hours or less to 0.70 for pavements on clays with no drains provided. When the CRCP is on drainable base provided with pavement underdrains, and the project is in the Oklahoma Panhandle (which receives the least amount of rainfall in the state), values of 1.25 to 1.20 may be used. On the other hand, Division 2, which receives the highest amount of rainfall in the state, may use Drainage Coefficient values ranging from 1.15 for drainable bases with pavement underdrains, to 0.70 for pavements with undrainable bases and without underdrains. The soil investigation report for the site is therefore important in choosing a reasonable value of C_d. Another factor to note is that Oklahoma soils are generally expansive clays. At sections where the pavement is on high fill, the change in moisture of the subgrade and the subsequent heaving and contraction of the soil affects the surfacing. The effect is severe when the pavement is in a cut section of the highway.

J = load transfer coefficient. Low values of J are for pavements with good load transfer characteristics and higher values for as the ability reduces. Pavements tied to PCC shoulders have increased stiffness and offer better load distribution characteristics. J values range from 2.3 for pavements with monolithic shoulders or tied curb and gutter, to 2.9 for pavements with ordinarily tied PCC shoulders. For pavements with asphalt shoulders and having some form of load transfer devices, the value of J ranges from 2.9 to 3.2. As a general guide, higher values of J should be used with low k-values, higher thermal coefficients, and large temperature variations. The Guide advises that each agency develop criteria for its own materials and environmental conditions.

k = composite modulus of subgrade reaction

$$= M_R/19.4 \qquad \ldots\ldots\ldots\ldots \qquad 4$$

where M_R is the Effective Roadbed Soil Resilient Modulus.

The Effective Roadbed Soil Resilient Modulus is a combined effect of the seasonal variations in soil moduli. It gives a representative value of the overall damage per year suffered by the pavement under the different moisture and freezing conditions. Factors that affect the value of k include subbase erosion and differential vertical soil movements. These factors may create voids underneath the surfacing resulting in loss of support and reduced pavement design life. Loss of support is accounted for by reducing the k value. For Portland Cement or asphalt cement treated base with good pavement underdrain, the factor ranges from 0.0 to 1.0. For Lime Stabilized and Unbonded Granular Materials, the range of the Loss of Support factor is 1.0 to 3.0. For Fine Grained or Natural Subgrade Materials, the value is from 2.0 to 3.0. [Ref. 1, 1993, Part II, Table 2.7].

In the design for thickness of slab, h, is at rather awkward positions in the equation. The value, h, can be solved in an iterative process. This does not look like an attractive assignment for hand calculation. A computer solution or nomographs are typically used to solve for h. A computer software called DARwin developed by AASHTO is one such time saving alternative.

Reinforcement Design

Volumetric changes in concrete result in cracks in concrete pavements. Steel is used in concrete to control cracks. The main reinforcement in CRCPs is the longitudinal reinforcing. Transverse reinforcing is also provided.

Longitudinal reinforcing steel design

To obtain the amount of longitudinal reinforcing to provide in a pavement, three conditions have to be satisfied. These conditions relate to the crack spacing, crack width and the stress in reinforcing steel. The crack spacing formula is derived to limit spalling and punchout. A maximum limit of 2.4 m is suggested to minimize spalling and a minimum of 1.0 m is suggested to minimize the chances of punchout. The crack width criterion also limits spalling and the control of water penetration. The criterion on steel stress is to limit steel fracture and limit excessive permanent deformation by limiting the stress to 75 % of the ultimate tensile strength [Ref. 1].

The formula for percentage of longitudinal reinforcement to satisfy the *crack spacing* criterion is

$$\bar{x} = \frac{1.32\left(1+\frac{f_t}{1000}\right)^{6.7} * (1+\phi)^{2.19} * \left(1+\frac{\alpha_s}{2\alpha_c}\right)^{1.15}}{\left(1+\frac{\sigma_w}{1000}\right)^{5.20} * (1+P)^{4.60} * (1+1000Z)^{1.79}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 5$$

The formula for minimum percentage of longitudinal reinforcement to satisfy *crack width* criterion is:

$$CW = \frac{0.00932\left(1+\frac{f_t}{1000}\right)^{6.53} * (1+\phi)^{2.20}}{\left(1+\frac{\sigma_w}{1000}\right)^{4.91} * (1+P)^{4.55}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 6$$

The minimum percentage of longitudinal steel to satisfy *steel stress* criterion is given by

$$\sigma_s = \frac{47300\left(1+\frac{f_t}{1000}\right)^{4.09} * \left(1+\frac{\Delta T_D}{100}\right)^{0.425}}{\left(1+\frac{\sigma_w}{1000}\right)^{3.14} * (1+P)^{2.74} * (1+1000Z)^{0.494}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 7$$

f_t = concrete indirect tensile strength. The indirect tensile test is covered under AASHTO T 198 and ASTM C496 test specifications.

ϕ = diameter of reinforcing bar or wire

α_s = steel thermal coefficient. The guide suggests a value of 5.0×10^{-6} in./in./^{0}F (8.00 m/m/^{0}C) unless more specific knowledge is available.

α_c = concrete thermal coefficient. The most significant factor affecting this value is the type of coarse aggregate. Other factors include the water-cement ratio, concrete age, richness of the mix and the relative humidity. Table 2.10 of the Guide gives recommended values of the concrete thermal coefficient, ranging from 6.6×10^{-6} in./in./^{0}F (10.56 m/m/^{0}C) to 3.8×10^{-6} in./in./^{0}F (6.08 m/m/^{0}C) for quartz and limestone respectively.

σ_w = tensile stress due to wheel load, (psi). This depends on the subgrade, the concrete slab thickness and the magnitude of the design wheel load. For a given Effective Modulus of Subgrade Reaction, k, and concrete slab thickness, h, the value of σ_w increases with increasing magnitude of wheel load. Figure 3.9 of the AASHTO Guide is a chart for estimating σ_w.

P = percent of steel

ΔT_D = design temperature drop (^{0}F) = T_H - T_L.

T_H = average daily high temperature during the month the pavement is constructed (^{0}F).

T_L = average daily low temperature during the coldest month of the year (^{0}F).

Z = drying shrinkage coefficient for PCC (in./in.)

Transverse reinforcing steel design

Transverse steel is provided to reduce longitudinal cracks in conditions where heaving, swelling and shrinkage may result in excessive longitudinal cracks. The percent of transverse steel in terms of spacing between the reinforcing bars is:

$$Y = \frac{A_s}{P_t h} \times 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad 8$$

where

Y= transverse steel spacing (inches)

A_s= cross-sectional area of transverse reinforcing (in. sq.)

P_t = percent transverse steel, and

h = the overall thickness of concrete (inches).

In Oklahoma, the transverse reinforcing for most projects is about 0.048% of the concrete cross-sectional area.

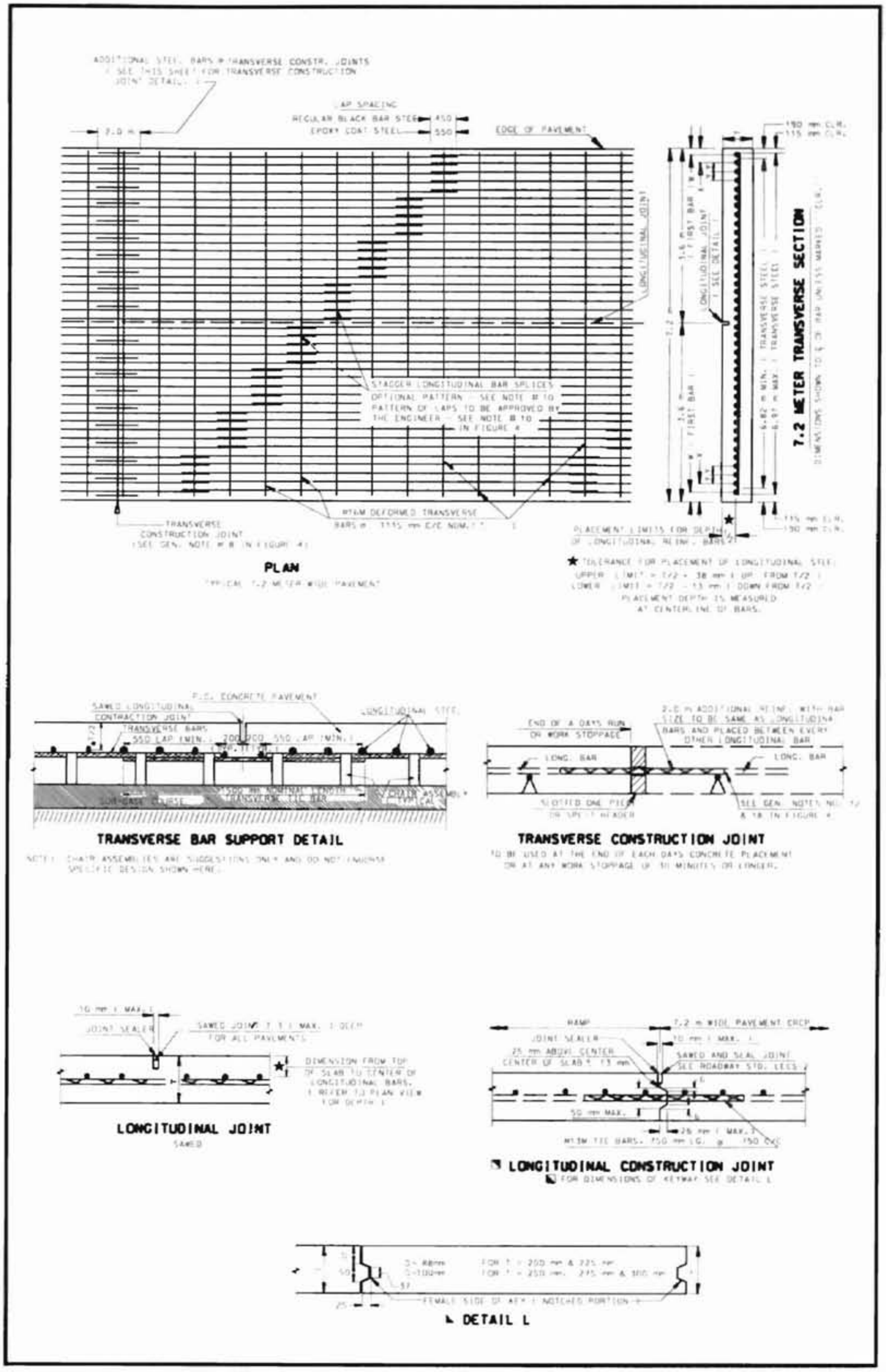

Figure 3. Reinforcing Steel bars.

PAVEMENT DESIGN DATA - (C.R.C.P.)

DESIGN TYPE	(mm) SLAB THICKNESS	BAR SIZE mm	7.2 METER WIDE CONCRETE PAVEMENT: SPACING (mm) W	X	Y	NO. OF BARS	kg/m2	DES. (1° @ V)	ENTRANCE & EXIT RAMPS: SPACING (mm) W	X	Y	NO. OF BARS	kg/m2	DES. (1° @ V)
A	225	#19M	146	298	200	36	8.76	0.61	146	298	200	18	8.76	0.61
B	250	#19M	146	250	180	40	9.63	0.61	125	266	180	20	9.63	0.61
C	275	#19M	146	275	165	44	10.47	0.61	125	260	162	22	10.47	0.61
D	300	#19M	146	298	150	47	11.15	0.60	146	292	144	24	11.30	0.60

QUANTITIES LISTED IN KILOGRAMS/SQUARE METER COLUMNS INCLUDES TRANSVERSE BARS AND LAPS BASED ON 9.1 METER (MINIMUM) LONGITUDINAL STEEL LENGTH.

THE SUCCESS OF THE WEAKENED PLANE CREATED BY THE SAWED LONGITUDINAL JOINT DEPENDS UPON ADHERENCE TO PLAN DIMENSIONS (KERF WIDTH AND DEPTH). THE KERF MUST EXTEND TO ONE-THIRD (1/3) PAVEMENT DEPTH TO GUARANTEE STRAIGHT LINE BREAKAGE. SAW CUT CAN BE MADE ANYTIME IN THE FIRST WEEK OF PAVEMENT LIFE. UNLESS A RAPID TEMPERATURE DROP IS EXPECTED. WHICH WILL CAUSE AN AIR TEMPERATURE DIFFERENTIAL OVER 11 °C. OR WILL MOVE THE AIR TEMPERATURE BELOW 4 °C WITH PROSPECTS OF IT REMAINING THERE OVER 3 HOURS. IF THE DESCRIBED DROP IN TEMPERATURE IS IMMINENT. SAWING THE JOINT MUST BE CARRIED OUT PRIOR TO THE TEMPERATURE DROP.

SAWED CONTRACTION JOINTS ON TIED P.C. SHOULDERS (1.2 m AND 3.0 m WIDE) SPACED AT 5.0 m C/C (1 JOINT) NO LOAD TRANSFER DOWELS ON SHOULDERS.

SAWED CONTRACTION JOINTS ON TIED P.C. SHOULDERS (1.2 m AND 3.0 m WIDE) SPACED AT 5.0 m C/C (3 JOINTS) NO LOAD TRANSFER DOWELS ON SHOULDERS.

GENERAL NOTES

1. LONGITUDINAL DEFORMED REINFORCING STEEL BARS SHALL CONFORM TO AASHTO M 31M. GRADE 420.
2. ALL TRANSVERSE BARS SHALL BE DEFORMED BARS SPACED AS SHOWN IN PLAN VIEW AND SHALL CONFORM TO AASHTO M 31M. GRADE 420.
3. ALL LONGITUDINAL BARS SHALL BE SPLICED A MINIMUM OF 450 MILLIMETERS AND HAVE A MINIMUM LENGTH OF 10.0 METERS. LONGITUDINAL BARS SHORTER THAN THE 10.0 METERS WILL BE NECESSARY FOR THE PURPOSE OF STARTING OR ENDING THE STAGGERED LAP PATTERN.
4. PAVEMENT WIDTH. THICKNESS AND THE CROWN OR CROSS SLOPE SHALL BE AS SHOWN ELSEWHERE IN THE PLANS.
5. EXPANSION JOINTS WILL NOT BE USED EXCEPT AT TERMINAL POINTS AS SHOWN IN THE PLANS FOR MAINLINE AND/OR SHOULDER PAVEMENT.
6. TRANSVERSE CONSTRUCTION JOINTS MAY BE FORMED BY HEADERS OTHER THAN SHOWN. BUT ONLY WITH PRIOR APPROVAL OF THE ENGINEER.
7. COST OF ALL STEEL, INCLUDING ADDITIONAL STEEL REQUIRED AT TRANSVERSE JOINTS AND SLEEPER SLABS AND COST OF ADDITIONAL CONCRETE FOR SLEEPER SLABS WILL NOT BE PAID FOR SEPARATELY BUT WILL BE INCLUDED IN THE UNIT PRICE BID PER SQUARE METER OF P.C. CONCRETE (CONTINUOUSLY REINFORCED).
8. VIBRATORY EQUIPMENT WILL BE REQUIRED TO ENSURE COMPLETE AND UNIFORM CONSOLIDATION OF CONCRETE AROUND THE CLOSELY SPACED STEEL MEMBERS. THE CONCRETE ADJACENT TO TRANSVERSE CONSTRUCTION JOINTS AND EXPANSION JOINTS SHALL BE VIBRATED WITH HAND MANIPULATED MECHANICAL VIBRATORS.
9. WHERE CHAIRS ARE USED. THE CHAIRS SHALL BE OF A TYPE APPROVED BY THE ENGINEER AND AT LEAST ONE CHAIR WILL BE REQUIRED FOR EACH 1.5 SQUARE METERS OF PAVEMENT.
10. NOT OVER 35 PERCENT OF THE REGULAR LONGITUDINAL STEEL SHALL BE SPLICED WITHIN ANY GIVEN AREA MEASURED 3.65 METERS TRANSVERSELY BY 750 MILLIMETERS LONGITUDINALLY.
11. THE TWO SECTIONS OF PAVEMENT AT THE BRIDGE APPROACH TERMINAL JOINT. EITHER FOLLOWING OR PRECEDING THE CONTINUOUSLY REINFORCED CONCRETE PAVEMENT. SHALL BE REINFORCED WITH SAME SIZE BARS. WITH STEEL SPACED THE SAME AS AND PAID FOR AS THE CONTINUOUSLY REINFORCED CONCRETE PAVEMENT.
12. AT TRANSVERSE CONSTRUCTION JOINTS THE REGULAR LONGITUDINAL BARS SHALL EXTEND BEYOND THE JOINT SO THAT THE BAR SPLICES FOR THE REGULAR LONGITUDINAL BARS WILL BE A MINIMUM OF 1.5 METERS FROM THE CONSTRUCTION JOINT EXCEPT AS PROVIDED IN SPECIAL PROVISIONS.
13. LAP SPLICES IN THE LONGITUDINAL REINFORCEMENT SHALL BE TIED OR OTHERWISE FASTENED SECURELY AND SHALL BE SECURED TO THE TRANSVERSE BARS BY WIRE TIE CLIPS AT SUFFICIENT INTERVALS TO MAINTAIN THE HORIZONTAL AND VERTICAL PLACEMENT SHOWN ON THIS STANDARD.
14. ENTRANCE AND EXIT RAMP DETAILS ARE TYPICAL ONLY. GEOMETRIC DETAILS AS TO ALIGNMENT. PAVEMENT WIDTH. THICKNESS AND CROSS SLOPE SHALL BE AS SHOWN ELSEWHERE IN THE PLANS.
15. THE SEQUENCE OF OPERATION IN PLACING THE ENTRANCE & EXIT RAMPS SHALL BE AS DIRECTED BY THE ENGINEER.
16. LEAVE OUT SECTIONS (OMISSIONS) WILL NOT BE PERMITTED. TEMPORARY BRIDGES WILL BE USED WHERE REQUIRED. COST TO BE INCLUDED IN OTHER ITEMS OF WORK.
17. LONGITUDINAL CONSTRUCTION JOINT IS TO BE USED ON PAVEMENT EDGES WHERE TIED SHOULDERS ARE CALLED FOR. AS WELL AS RAMP TERMINALS AND STREET INTERSECTIONS. UNLESS OTHERWISE NOTED.
18. IN ALL DETAILS THE TRANSVERSE STEEL IS SHOWN BELOW THE LONGITUDINAL STEEL. THIS IS THE RECOMMENDED PLACEMENT FOR LONGITUDINAL STEEL SUPPORTED ON TRANSVERSE STEEL & CHAIR ASSEMBLIES. TRANSVERSE STEEL PLACED AFTER MECHANICALLY PLACED LONGITUDINAL STEEL WILL BE PLACED ON TOP OF THE LONGITUDINAL STEEL.
19. FEMALE KEY (NOTCHED PORTION) SHALL BE CONSTRUCTED ON THE FIRST POUR EDGE AT ALL TIMES. ON SLIP FORM OPERATIONS. FEMALE KEYS WILL BE CONSTRUCTED ON BOTH EDGES.
20. WHEN SLEEPER SLAB IS LOCATED UNDER THE JOINT BETWEEN THE APPROACH SLAB AND THE 10 METER CRCP SECTION. IT SHALL BE CONSTRUCTED PRIOR TO THE INSTALLATION OF THE BRIDGE APPROACH TERMINAL JOINT. (SEE PLANS)

Figure 4. Design Data and General Notes.

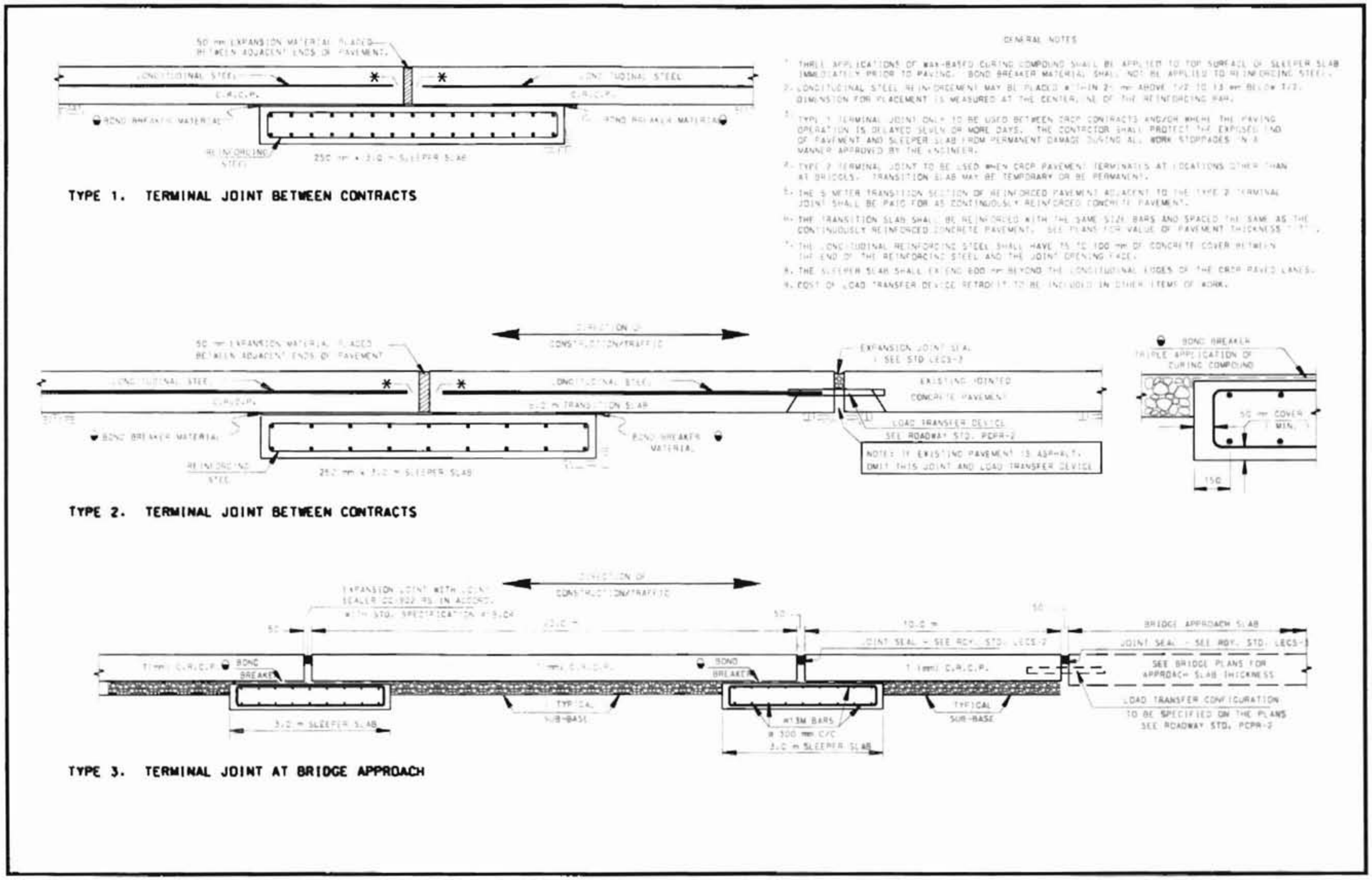

Figure 5. Terminal Joints(1996 Specifications)

Comments

The assumption in design of a value for the crack spacing and the crack width does not guarantee that those values are necessarily going to be obtained for all the crack spacings and widths on the pavement. With so many variables in operation and the limitations of construction, the crack widths and spacing can only be expected to be within a range of values. In the survey the average of crack spacings and crack widths are given to convey the general range of values on the site.

The value of any parameter used in the design needs to be chosen based on the material to be used and the soil investigation report. The importance of using representative values cannot be overemphasized. For example, in the design of project number IM-40-2(119)040, Beckham County, I-40, the designer used a Drainage Coefficient of 1.25, the highest one can assume for an excellent, drainable base and subgrade that will be subjected to moisture levels approaching saturation for less than 1 percent of the time. During the visit to the CRCP sites, it was observed that repairs had been done at some locations and extra measures put in place to make the pavement drainable because the base was not draining easily on the project.

For the same project, the choice of Initial Serviceability Index of 4.50 and a Final Serviceability Index of 2.50 means ΔPSI is 2.00. The AASHTO design guide suggests an index of 2.5 or higher for the design of major highways. The level of importance of I-40 will warrant a reliability of 95 to 99 percent that the pavement will perform adequately; since the risk interruption of high volume traffic on I-40 is not desirable. The design file shows that a 90 percent level was used. The underestimation of the design needs of the highway tends to reduce the useful life span of the projects and lead to the early signs of failure in CRC projects.

The selection of subbase materials and thicknesses, or a specific material and thickness for use on a project requires economic evaluation based on availability of local materials, the modulus of elasticity and erodability factor the cost of stabilizing agents, material grading and processing. The selected subbase-on-subgrade system should result in a pavement with stable foundation and improved load carrying capacity in the presence of moisture. Stabilized materials are more stable under frost action than natural (unstabilized) materials. Natural materials lose part of their strength as a result of pumping and erosion in the presence of moisture, and undergo consolidation during their service life. Stabilized materials are therefore preferred under CRCPs [Ref. 7].

CHAPTER 3

CONDITION OF CRCPs IN OKLAHOMA

Introduction

Irregularities of transverse crack spacings, punchouts, water bleeding and pumping were some of the distress factors noted during the field investigation of CRCPs. These irregularities do not fit neatly in the textbook description spacing, crack widths and crack patterns of CRCPs. The field investigation was conducted to compare the predicted and observed behavior of CRCPs in Oklahoma.

The method used in the field investigation and data collection of the present service condition of CRCPs in the state is the focus of this chapter. Distress identification parameters used during the field investigation are defined to give a common understanding of various terms in the discussion. This is followed by a general overview of the condition of CRCPs in the eight divisions in Oklahoma. More detailed information on the condition of each CRC project visited during the field investigation is in Appendix A. A copy of the form used for recording observations during the field investigation is in Appendix B.

Method of survey

One team conducted the survey. This is important for consistency in opinion since user perception of quality and comfort of ride is subjective and not easily quantifiable. The survey team was frequently accompanied by personnel from the

Research and Development Division of ODOT who provided background information about some projects.

The field study did not involve any lane closures nor traffic control. The survey was conducted from the shoulder of the pavements in a moving hazard-warning vehicle with the caution lights turned on. Generally, the survey at a CRCP project started with an examination of the terminal joint or viewing the end joint for operational effectiveness of the wide flange steel beams, joint filler, and jointed concrete slab arrangement. See Figure 5 for the types of terminal joints used in CRCPs. The vehicle then traveled at a slow speed of about 10 km/h along the shoulder. The team viewed the pavement from inside the moving vehicle. After observing the general condition and crack pattern of the pavement from the shoulder, the vehicle moved to the pavement and traveled at the posted speed. Close to the middle of the project, the speed was lowered to around 10 km/h and the visual examination from the shoulder repeated for a short distance to compare the state of the pavement with the beginning. The end of the project and terminal joint were also examined. For comparison, any areas of distress or uncharacteristic section were also observed. Photographs of unusual features and representative sections were taken for each project. The survey was repeated in the opposite direction if CRCP was present.

Condition Indicators

Table 3 of "Distress Identification Manual for the Long-Term Pavement Performance Project" by National Research Council, Strategic Highway Research Program (SHRP-P-338) lists many condition indicators for CRCPs. For the survey of the CRCPs in Oklahoma the following indicators were used. The definitions of distress and numerical limits of severity are as follows:

1) *Longitudinal Cracks* - cracks predominantly parallel to the pavement centerline.

Severity Levels

Low:	Crack widths <5 mm, no spalling, and there is no measurable faulting; or well sealed and with a width that cannot be determined.
Moderate:	Crack widths ≥ 5 mm and < 15 mm; or with spalling < 75 mm; or faulting up to 15 mm.
High:	Crack widths ≥ 15 mm; or with spalling ≥ 75 mm; or faulting ≥ 15 mm.

How to Measure: Record length in meters of longitudinal cracking at each severity level.

Also record length in meters of longitudinal cracking with sealant in good condition at each severity level.

2) *Transverse Cracks* - cracks predominantly perpendicular to the pavement centerline.

This cracking is expected in a properly functioning CRCP. "Y" cracks are routine, naturally occurring defects, and shall be counted as a single occurrence of a transverse crack.

Severity Levels

Low:	Cracks that are spalled along ≤ 10% of the crack length.
Moderate:	Cracks that are spalled along > 10% and ≤ 50% of the crack length.
High:	Cracks that are spalled along > 50% of the crack length.

How to Measure: Record the total number of transverse cracks within the survey section, including those that are not distressed. Record separately the number and length in meters of transverse cracking at each severity level. Length recorded, in meters is the total length of the crack. "Y" cracks shall be considered as single cracks. The sum of the individual crack lengths shall be recorded.

3) *Scaling* - deterioration of the upper concrete slab surface, normally 5 mm to 15 mm depth, and may occur anywhere over the pavement.

Severity Levels

Not Applicable

How to Measure: Record the number of occurrences and the square meters of affected area.

4) *Polished Aggregate* - occurs when surface mortar and texturing is worn away to expose coarse aggregate.

Severity Levels

Not applicable. However, the degree of polishing may be reflected in a reduction of surface friction.

How to Measure: Record square meters of affected surface area.

5) *Popouts* - when small pieces of pavement break loose from the surface, normally ranging in diameter from 25 mm to 100 mm and depth from 15 mm to 50 mm.

Severity Levels

Not Applicable. However, severity levels can be defined in relation to the intensity of popouts as measured below.

How to Measure: Record number of popouts per square meter.

6) *Blowups* - localized upward movement of the pavement surface at transverse joints or cracks, often accompanied by shattering of the concrete in that area.

Severity Levels

Not Applicable. However, severity levels can be defined by the relative effect of a blowup on ride quality and safety.

How to Measure: Record number of blowups.

7) *Transverse Construction Joint Deterioration* - the condition where a series of closely spaced transverse cracks or a large number of interconnecting cracks occur near the construction joint.

Severity Levels

Low: No spalling or faulting within 0.5 m of construction joint.

Moderate: Spalling < 75 mm exists within 0.5 m of construction joint.
High: Spalling ≥ 75 mm and breakup exists within 0.5 m of construction joint.

How to Measure: Record number of construction joints at each severity level.

8) *Patch / Patch Deterioration* - portion, greater than 0.1 sq. m, or the entire original concrete slab that has been removed and replaced, or additional material applied to the pavement after original construction.

Severity Levels

Low: Patch has at most low severity distress of any type; and no measurable faulting or settlement at the perimeter of the patch.
Moderate: Patch has moderate severity distress of any type; or faulting or settlement up to 5 mm at the perimeter of the patch.
High: Patch has a high severity distress of any type; or faulting or settlement ≥ 6 mm at the perimeter of the patch.

How to Measure: Record number of patches and square meters of affected surface area at each severity level, recorded separately by material type--rigid versus flexible.

Note: Panel replacement shall be rated as a patch. New transverse cracks shall be rated separately. Any sawn joints shall be considered construction joints and rated separately.

9) *Punchout* - the condition where the area enclosed by two closely spaced (usually less than 0.5 m) transverse cracks, a short longitudinal crack, and the edge of the pavement or a longitudinal joint (also included "Y" cracks) exhibit spalling, breakup, and faulting.

Severity Levels

Low: Longitudinal and transverse cracks are tight; and may have spalling < 75 mm or faulting < 5 mm. Does not include "Y" cracks.
Moderate: Spalling ≥ 75 mm and < 150 mm or faulting ≥ 5 mm and < 15 mm exists.

High: Spalling $\geq$ 150 mm or concrete within the punchout is punched down by $\geq$ 15 mm or is loose and moves under traffic.

How to Measure: Record number of punchouts at each severity level. The cracks which outline the punchout are also recorded under "Longitudinal Cracking" (CRCP 2) and "Transverse Cracking" (CRCP 3).

10) *Spalling of Longitudinal Joints* - cracking, breaking, chipping, or fraying of slab edges within 0.5 m of the longitudinal joint.

Severity Levels

Low: Spalls less than 75 mm wide, measured to the center of the joint, with loss of material or spalls with no loss of material and no punching.

Moderate: Spalls 75 mm to 150 mm wide, measured to the center of the joint, with loss of material.

High: Spalls greater than 150 mm wide, measured to the center of the joint, with loss of material.

How to Measure: Record length in meters of longitudinal joint spalling at each severity level.

11) *Water Bleeding and Pumping* - seeping or ejection of water from beneath the pavement through cracks or joints. In some cases the condition is detectable by deposits of fine material left on the pavement surface, which were eroded (pumped) from the support layers and have stained the surface.

Severity Levels

Not Applicable. Severity levels are not used because the amount and degree of water bleeding and pumping change with varying moisture conditions.

How to Measure: Record the number of occurrences of water bleeding and pumping and the length in meters of affected pavement.

12) *Longitudinal Seal Damage* - any condition which enables incompressible materials or a significant amount of water to infiltrate into the joint from the surface.

Typical types of joint seal damage are:

Extrusion, hardening, adhesive failure (bonding), cohesive failure (splitting), or complete loss of sealant.

Intrusion of foreign material in the joint.

Weed growth in the joint.

Severity Levels

Not Applicable.

How to Measure: Record number of longitudinal joints that are sealed (0, 1, 2). Record length of sealed longitudinal joints with joint seal damage as described above.

Overview of Survey Findings

Failure in this overview will be defined as structural deficiency or functional obsolescence. Failure in CRCPs is considered to have occurred when there is a loss of continuity and loss of support of a section of pavement resulting in a localized permanently depressed piece of the roadway. Punchout in the pavement is one type of failure. Transverse cracks and longitudinal cracks do not constitute failure or sign of impending failure. Combination of cracks, and subbase or subgrade weakness may increase the chances of failure, although, individually, these factors may not result in a punchout.

Out of the twelve condition indicators listed earlier there was only one case of light *scaling* observed. There was no case of *polished aggregate* or *blowups*. *Popouts* were infrequent. There were *longitudinal cracks*, *transverse cracks* and *transverse* *construction joint deterioration* on some projects. The most frequent distress type observed was *punchout*. At some locations the repair to punchouts were experiencing *patch deterioration*. The following discussion will be presented according to what was observed in each of the eight Divisions of the state. The Divisions in the state are shown in Figure 6.

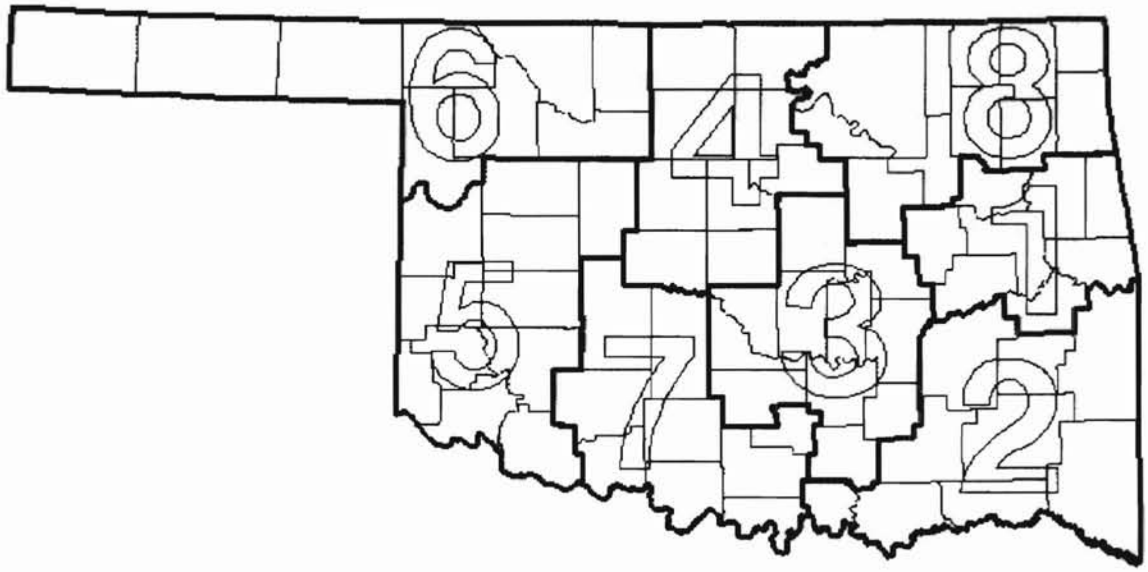

Figure 6. ODOT Highway Divisions in Oklahoma

Division 1 has eleven CRCP project locations. The first CRCP constructed in the Division is a section of I-40 in Muskogee built in 1973. The most recent one is on US 62 constructed in 1997. CRCP has been used on some interstate highways, US highways and one state highway, SH 165. The pavements were either 225 mm or 250 mm thick with the exception of US 62/75 in Okmulgee which is 200 mm thick. The concrete is generally reinforced with 0.61 % longitudinal steel and 0.08 % transverse steel. The subbase and subgrade are usually of 100 mm OGPC and treated lime or fly ash respectively. Most of the pavement shoulders were of PCC. Six of the pavements have edge drains and five do not. Nine out of the eleven projects in the Division are performing satisfactorily. One of the two pavements in the Division which has severe condition indicator levels is [IR-40-6(220)298] on I-40 built in 1989. This 250 mm thick concrete surfacing is on an interstate with very high volume of truck traffic. The pavement has one longitudinal crack, some spalling, and about six repairs. Project number I-40-6(86) is the second of the two projects. It also has the high volume truck traffic of I-40 near Warner. This project has longitudinal cracks, spalling along cracks, punchouts of more than 4 per kilometer, full lane repairs that are over 10 m long and a large patch of asphalt overlay that is about 150 m long. This pavement was built in 1971, but even after twenty eight year of service it is still usable despite the distresses previously noted.

The rest of the projects have no longitudinal cracks. Transverse cracks generally have either no spalling or less than 10% spalling along the crack length. There are clustering of cracks on some projects and some Y cracking as well, but the level of severity is low and is no cause for concern. Scaling, popouts and blowouts are a rare occurrence.

Division 2 has eight CRCP project locations. The first CRCP in the Division was constructed in the mid-eighties and the last was in 1994. They are all located on US 69. Three of the projects have 225 mm thick cement concrete surfacing reinforced 0.5% and 0.08% longitudinally and transversely respectively and have no side drains. The other five projects in the Division have 250 mm thick cement concrete surfacing reinforced with 0.61% and 0.07% longitudinal and transverse steel respectively. Four of the five 250 mm thick CRCPs have side drains. All the pavements have tied PCC shoulders.

Three 225 mm thick CRCPs with no side drains in this Division have severe levels of transverse cracks, clustering and Y-cracking, spalling along the cracks, and numerous punchouts and repairs. These projects are F219(35), F-299(45) and F299(35). The severe distress levels on these projects may be the result of poor construction or poor design or a combination of the two. It is not easily evident in a visual field investigation to determine the quality of construction, the level of compaction attained in the subbase and base, the checks done on the concrete or the time of construction. It is much easier to look at the design. One striking observation is the absence of base and subbase underdrain. ODOT Materials Division's soil investigation report presented on project number F-299(45) states that "Poor surface drainage and ponded water were evident in several areas of Rexor Soils during the soil survey." The liquid limit of greater than 30 and plasticity index greater than 12 for the soils suggest the soil has high shrink-swell characteristics. Pavement underdrain, as shown in the ODOT standard CRCP drawing, is advisable under such poor subgrade drainage conditions. The poor drainage may have reduced the ESAL capacity of the pavements, explaining the numerous distresses of these projects in only the ten years of service. A special study of this project may be very helpful in future designs and construction of CRCPs. A detailed study of the design, looking at the subbase and base material properties, drainage, the structural design of the pavement, the time of construction, methods used and the construction logs may reveal the cause of the mass failures so uncharacteristic of CRCPs.

None of the other CRCPs in Division 2 has more than two punchouts and most of them have no punchouts. Transverse cracks have low severity levels and virtually no spalling at the cracks.

Division 3 has two CRCPs, one on I-40 east of Okemah built in 1985 and the other on SH 3 in Ada constructed in 1989. Project number IR-40-5(169) on I-40 is a very high volume truck traffic route. The effects of traffic over the years has resulted in the high deterioration of the pavement. The design file does not show any calculations. The construction drawings specify 225 mm thick reinforced concrete surfacing with 0.5% longitudinal and 0.08% transverse steel. The foundation is bituminous base coarse aggregate on the existing base and no side underdrains. See Appendix C. No soil report was available to check the parameters used for the pavement foundation and surface course calculations. For a pavement with no underdrain, in this region of the state that experiences a good amount of rainfall per year, and has high truck traffic volume, the 225 mm may be low. This may explain why the pavement has had about thirty repairs and punchouts, some repairs going a whole lane wide. On the other hand, the CRCP on SH 3 has no severe conditions in either direction.

Division 4. Five of the CRCP projects in Division 4 were visited in the survey. Three of these are on state highway SH 74, built in 1992. They have 250 mm thick PCC surfacing with 0.61% longitudinal and 0.07% transverse steel. The surfacing is founded on 100 mm open graded and 300 mm Type B Aggregate. See Appendix C. The pavements have concrete shoulders and all have edge drains. The projects were all performing satisfactorily – none of the condition indicators were severe, no *longitudinal cracks*, no *scaling*, no *polished aggregates*, no *popouts*, and no *blowups*. There were no *transverse construction joint deterioration*, no *patches*, and no *punchouts*. There was no water bleeding through the cracks and no pumping seemed to have taken place. No *spalling of longitudinal joints* and no *longitudinal seal damage* has occurred on any of the three projects. Transverse cracks were generally low to moderate in severity level.

There was some Y-cracking but low spalling along the cracks. This is a very heavily trafficked highway with little truck traffic.

The two other projects surveyed in Division 4, IR-35-4(115) and MAIR-35-4(111), are on interstate I-35 in Logan and Noble counties respectively. These pavements carry very heavy truck traffic. They were constructed in 1993-94. Both have 250 mm thick cement concrete with 0.61% longitudinal and 0.07% transverse steel. The shoulders are of PCC tied to the CRC surfacing. IR-35-4(115) is on 75 mm asphalt concrete Type A and MAIR-35-4(111) is on 100 mm econocrete. Econocrete is PCC mix with about half the amount of cement used in normal mix concrete. The project in Logan County has no pavement underdrains but MAIR-35-4(111) in Noble County has the 100 mm pipe and underdrain arrangement. No longitudinal cracks have occurred in these projects. One interesting characteristic is the consistency in the sympathetic crack at some sections of the projects. Sympathetic cracking is when the transverse cracks in the pavement lined up with the sawed joints in the shoulders. Another noticeable feature is the consistency in the defective construction joints. There were some Y-cracks and clusters at few places of the projects. Some of the on/off ramps have small asphalt patches, indicating locations of failures.

Division 5 has only one location with CRCP and is on interstate highway I-40. The traffic here is heavy and the truck volume is high. The project was built in 1993. The pavement is 250 mm thick concrete with 0.61% longitudinal and 0.07% transverse steel. The shoulders are unreinforced cement concrete doweled to the pavement. The surfacing is founded on 100 mm Open Graded Portland Cement (OGPC) base and 100 mm aggregate with edge drains.

There were no longitudinal cracks on the westbound lanes. The eastbound lanes have some longitudinal cracks. There has been punchouts in both directions, which have resulted in the full-depth, full-width repairs done in both directions of travel. See Appendix D. There are many Y-cracking and curved cracks. There is spalling along the cracks in both directions of travel. Additional drain has been installed at one of the repairs to increase the drainage of the pavement.

Division 6 has two sites with CRCPs. They are both on US highways. The one in Boise City, built in 1996, is 250 mm thick PCC with 0.61% longitudinal and 0.07% transverse steel. The shoulders are built integral with the surfacing, forming one unit of continuously reinforced concrete. The subbase is 100 mm Open Graded Portland Cement and 300 mm Select, with edge drains. The other CRCP in the Division is part of Federal Aid Project NH-8N(001). Part of the project is in doweled jointed concrete. Only a section of project was built using CRC. The CRC section has 250 mm thick concrete with 0.61% longitudinal and 0.07% transverse steel. The CRC surfacing is laid on 100 mm asphalt concrete type A, which is on 200 mm fly ash, modified subgrade. There are no underdrains to the pavement. These pavements are in the Oklahoma Panhandle, which receives the least amount of rainfall per year.

Both pavements are new. NH-8N(001) was under construction and has had no traffic in it at the time of the survey. The transverse cracks were not visible on the top and barely visible at the edge. MAF-350(11) has been opened to traffic for two years. The pavement carries heavy traffic. Despite that, transverse cracks are barely visible. The pavement is in good condition. No defects were observed.

Division 7 has four projects constructed with CRCP. Three were constructed in 1970/71 on interstate highway I-35 using 250 mm thick concrete with 0.61% longitudinal and 0.08% transverse steel. The shoulders are all constructed with asphalt concrete. The subbase is 100 mm fine aggregate bituminous base on lime treated subgrade. The fourth project is on a major urban highway (Rogers Lane). It is a two-lane dual carriageway with raised median and outer curbs but no shoulders. The pavement is 225 mm thick concrete with 0.61% longitudinal and 0.08% transverse steel. The concrete surfacing is on 150 mm type B asphalt concrete subbase and 150 mm lime treated subgrade.

The three projects on I-35 are in good enough shape to continue serving traffic for a few more years. The pavements have longitudinal cracks some locations and the transverse crack widths are moderate to severe at some locations. Punchouts are patched at a few locations and other areas have been completely overlaid with asphalt concrete. Rogers Lane CRCP is problem free.

Division 8 has the largest number of projects constructed with CRCPs. The projects are on interstate highways, US highways, on the National highway system and on state highways. The time of construction vary from 1973 to as recently as 1998 when the survey was in progress. Two projects were constructed in 1973 and 1974 and have 200 mm thick concrete with 0.61% longitudinal and 0.08% transverse steel. The shoulders are asphalt concrete. The subbase is 125 mm fine aggregate bituminous base. There were 225 mm thick concrete surfaced pavements with 0.8% transverse steel and generally have concrete shoulders and no underdrains. Twelve projects have 250 mm thick concrete and mostly reinforced with 0.61% longitudinal and 0.08% steel. Most of these have edge drains.

On project number STP-66B(306) in Rogers County there is one patch in each direction of travel, about 10 m long, and they go across the pavement and shoulders. These may be sections found to be defective at the time of construction and therefore had to be sawed out and reconstructed. There is a patch, about 1 m^2, on SH-33. With the exception of these locations where patches indicate repair, Division 8 has very little problem with CRCPs.

Summary

Based on the rating parameters and condition evaluation factors discussed above under "Condition Indicators", the condition of CRCPs in the state is generally very good. Throughout the state, CRCPs have performed well under the various traffic and environmental conditions. The survey as a whole gives a good impression of the performance of CRCPs. Most of the pavements have little to no sign of failure. Some older projects on sections of I-35 have performed quite well under the heavy vehicular traffic and high volume highway.

Transverse cracks were fairly straight across the pavement, but there were curved cracks on some projects. Clustered crack patterns were also observed on some projects. Transverse crack spacings were generally around 1 m although some sites have spacings closer and others greater than that. Crack spacings seem to depend on factors other than just the age of the pavement. Some pavements have crack spacing greater than others that are older than they are. Crack widths, on the other hand, seem to depend on the age of pavement and traffic volume. The general difference between the pavements is the relatively larger crack widths of the older pavements. Pavements with high-traffic-volume also tend to have wider crack widths. Spalling along transverse cracks seem to be greater on pavements with high truck traffic. The older pavements on the interstate highways generally have a lot of spalling at the transverse cracks. Longitudinal cracking seldom occurred on the newer pavements. There was only one incident of longitudinal faulting observed and that was over a length of about 4 meters. There were isolated projects that have conditions similar to pumping.

Failure of the pavement generally resulted in punchouts. For a few projects, the exit/entrance ramps were locations of some form of failure, mostly punchout. Where the area in distress is less than 1 m^2, patching by asphalt concrete is common. For a larger area of failure, concreting using full-depth cut and replacement is used. See Appendix E for photographs representing the sequence of construction. Where asphalt is used to patch the punchout, it is not certain whether that is meant to be the permanent repair or a temporary measure. For some of the very old CRCP projects, there were sections of more than 100 meters which have been overlain with asphalt, but these pavements have served for twenty years of design life and still serviceable.

Terminal joints were generally well constructed. For a few projects the lengths of jointed sections specified in the terminal joint arrangement have been reversed in the construction. Some end joints with structural beam arrangement have performed well. At locations where the wide flange steel beam end joints have been replaced by the new end joint arrangement proposed by ODOT, the new joints have performed well.

Rather noticeable is the very high punchout rate for projects in Division 2. Project # F219(35) from Caddo to Armstrong and also F299(35) have a very high number of failures uncharacteristic of CRCP in any other project in the state. One obvious reason for this is the absence of side underdrain and fabric to separate the 'drainable base' from the subgrade. When the drainable base is placed directly on the subgrade, the presence of moisture in the subgrade and traffic on the surface work together to cause the subgrade to move into the open graded base. When this action is repeated over a period of time the surfacing concrete and base materials lose support and become prone to severe cracks and punchouts. The current standard ODOT drawings for CRCPs show drains under the pavement. See Figure 2. The base and side underdrain are covered with fabric, allowing extra fabric to wrap around the open graded base and back into the underside of the surfacing. For the above mentioned problem projects, the drains are omitted in the construction drawings. Details of the condition of all the CRCP locations visited are in Appendix A.

CHAPTER 4

OBSERVATION AND RECOMMENDATIONS

Most of CRCP constructed in Oklahoma State by August 1998 were inspected and the condition noted. From the survey conducted, watching new construction as well as repairs in progress, interpreting the data collected and reviewing the design files on the projects the following observation and recommendations were made:

- The overall performance of CRCP in Oklahoma State is excellent.
- The primary failure mode in CRCP is punchout as a result of loss of support combined with development of cracks.
- In the CRCP design files from ODOT, some projects were designed to using the method outlined in AASHTO Guide for Design of Pavement Structures. However, the calculation of the number of ESALs is not what AASHTO uses in the equation for design. The difference between values obtained by the AASHTO and ODOT methods and how they affect the design need to be investigated.
- Pavement condition is a function of accurate field survey, data collection, adequate design, strict construction control, traffic conditions, environmental factors, and age. It is, therefore, recommended that proper attention be given to data for design, including the soil investigation report and specifications.
- It is recommended that ODOT investigates the repair of punchouts by the following two step process:

1. **Restore support** by forming a network of core holes with 50 mm diameter core barrel at 300 mm centers which will be pressure-grouted, a system similar to foundation underpinning, and

2. **Restore load transfer** across crack by cutting out or milling a section of the pavement in the diagram, placing dowel bars and concreting. Refer to "Concrete Pavement Rehabilitation Guide for Load Transfer Restoration", U.S. Department of Transportation, Federal Highway Administration publication number FHWA-SA-97-103.

The advantage of the above procedure is that it will require less labor, less heavy equipment, will be faster to complete, and will open the highway to traffic within a day. The present method of concrete repair involves sawing the whole section of pavement for reconstruction. See Appendix D.

- Apart from the normal expansion and contraction of the pavement there is a permanent "growth" of the continuously reinforced concrete slab. This may be the result of incomplete contraction because of incompressible materials entering the cracks. The terminal joint design should take into account the normal expansion and contraction expected from temperature changes as well as this "growth" of the pavement.
- Although some of the terminal joints constructed using wide flange beam set into a sleeper slab are still functioning as expected, it is recommended that the design in the Ooten, Strep report [Ooten and Strep, 1992], which requires no wide flange beams, be used for future projects. The no-flange terminal joints are easier to construct, maintain, and repair.
-

- The performance of CRCP is heavily affected by the construction practice. Inadequate preparation of the subgrade may affect the performance of the pavement. Since most of Oklahoma is clay with highly expansive characteristics, it is recommended that the base and subbase should be well drained. Construction joints are also especially vulnerable to early failure. Faults were generally at construction joints. It is recommended that additional care and steps be taken at the end of the day's pour and when there is equipment break down. These are the times when quality of work is most susceptible to be low. Quality control of concrete is needed in the construction process to achieve the required compressive strength.

Maintenance is important to the optimal operation of CRCPs. Maintenance may take the form of "do-nothing" or may be "preventive". It may also be rehabilitation, and that may be light, medium, or heavy. It is recommended that preventive maintenance be adopted because it is the least expensive. Preventive maintenance techniques need to be employed if the pavement is to go the full distance in the design life and far beyond. CRCP has been known to serve far beyond the design life but the issues of drainage, prompt attention to loss of support, and prompt steps to restore loss of load transfer should be paramount in the efforts to keep the high performance of CRCP in Oklahoma.

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APPENDIXES

APPENDIX A	Condition of Projects
APPENDIX B	Data Collection Sheet Project Location Maps
APPENDIX C	Pavement Cross-Section Data Typical Pavement Section
APPENDIX D	Full-Depth Repair: Pictorial Sequence

APPENDIX A

CONDITION OF PROJECTS

CRCP.1		**Survey date:**	**July 23, 1998**
Division:	**1**	**County:**	**Okmulgee**
Project #:	**MABRF-53(141)**	**Location:**	**US62/US75**

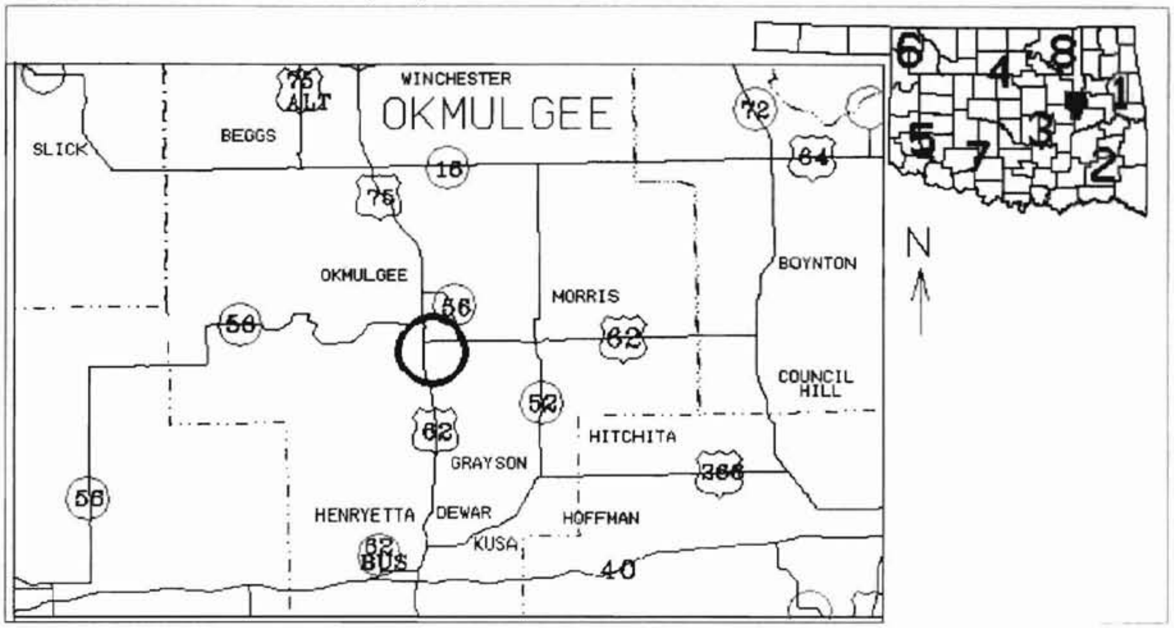


Figure A1. Location Map

Direction of travel of Survey Team: Southbound

Transverse crack spacings range from 0.9 to 2.0 m. The crack widths were from 0.25 to 0.40 mm. The crack widths are smaller after the bridge in the last third of the project. There was light spalling at some cracks. There were few clustered cracks, but no scaling no polished aggregates, no blowups and no transverse joint construction deterioration. There was one longitudinal crack of about 25 m length. There was only one punchout at a cross-over and a 0.3 m^2 repair. These two points of distress are not indicative of the performance of this project. The skid grooves across the pavement were quite deep at some sections. The project as a whole is in a very good condition. The ride was good. See Figures A2 and A3.

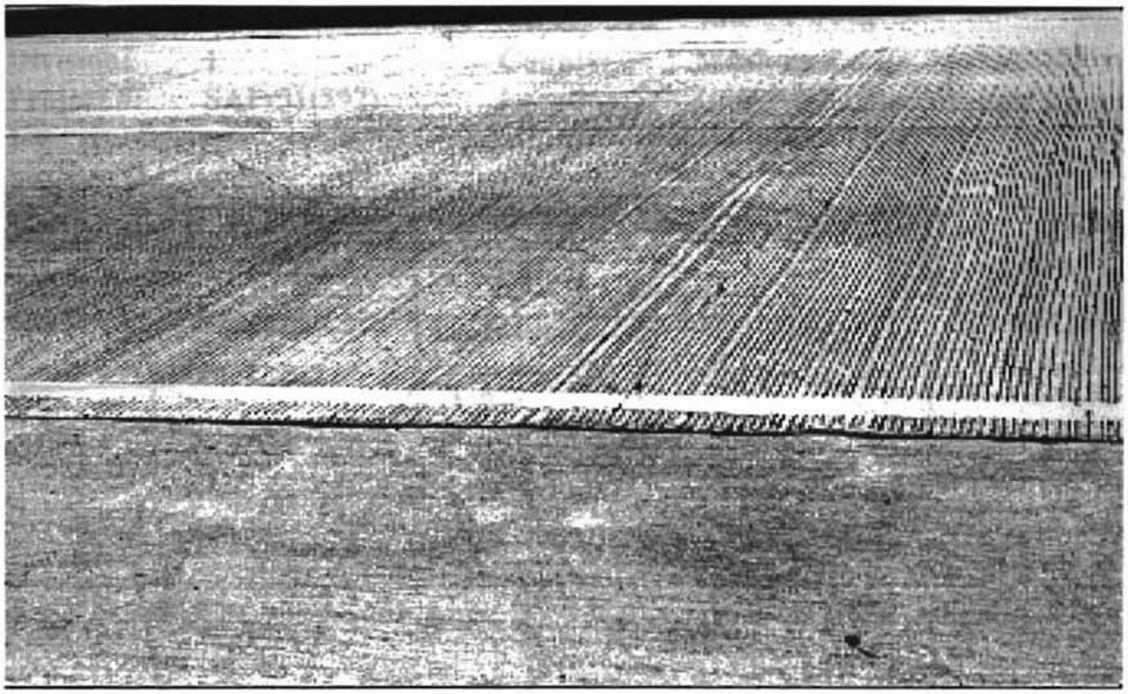


Figure A2. Typical view of MABRF-53(141)

Figure A3. The longitudinal crack in MABRF-53(141)

Direction of travel of Survey Team: Northbound

This is not a CRCP.

CRCP.2 | **Survey date: July 23, 1998**
Division: 1 | **County: Muskogee**
Project #: SAP-51(392) | **Location: US69/US64 interchange**

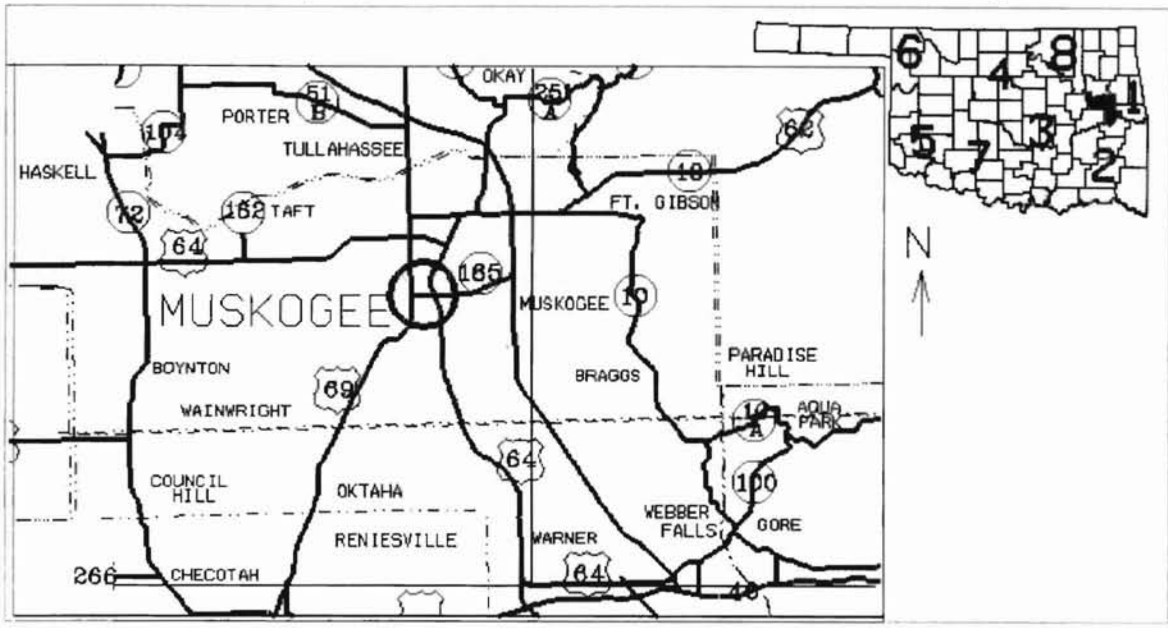


Figure A4. Location Map

Direction of travel of Survey Team: Northbound on US69

The spacing of transverse cracks in the first third was between 4.5 m. The spacing was about 2.2 m in the central third of the project. There were some Y-cracks, but no discoloration along the cracks. There were no spalling, no punchouts and no repairs. There were no longitudinal cracks, no blowups and no transverse construction joint deterioration.

Direction of travel of Survey Team: Southbound on US69

Transverse crack spacings were between 1.8 and 2.0 m. Some Y-cracking was observed. There were no longitudinal cracks, no spalling, no punchouts, and no repairs. No blowups were observed and no transverse construction joint deterioration. No bleeding or pumping was observed. The Terminal Joints were not damaged. The ride was excellent. See Figure A5.

Direction of travel of Survey Team: Eastbound on US64

The Terminal Joint at the beginning was not damaged. Transverse crack spacings were about 2.0 m. There was some Y-cracking. Crack widths were 0.25 to 0.40 mm. There were no construction joint failures. There were no spalling, no punchouts, and no repairs. There were no longitudinal cracks and no damage to the Terminal Joint at the end of the CRCP. The ride on the CRC was excellent.

Direction of travel of Survey Team: Westbound on US64

The pavement has transverse crack spacing and Y-cracking similar to the eastbound lanes. Crack widths were slightly wider, about 0.30 to 0.60 mm. There were no longitudinal cracks, no punchouts and no repairs. The Terminal Joints at both ends were not damaged and the ride was excellent. See Figure A6.

Figure A5. Typical view of SAP-51(392) southbound

Figure A6. Typical view of SAP-51(392) westbound.

CRCP.3		**Survey date:**	**July 23, 1998**
Division:	**1**	**County:**	**Muskogee**
Project #:	**MAFEGC-410(35)**	**Location:**	**SH-165 near Muskogee**

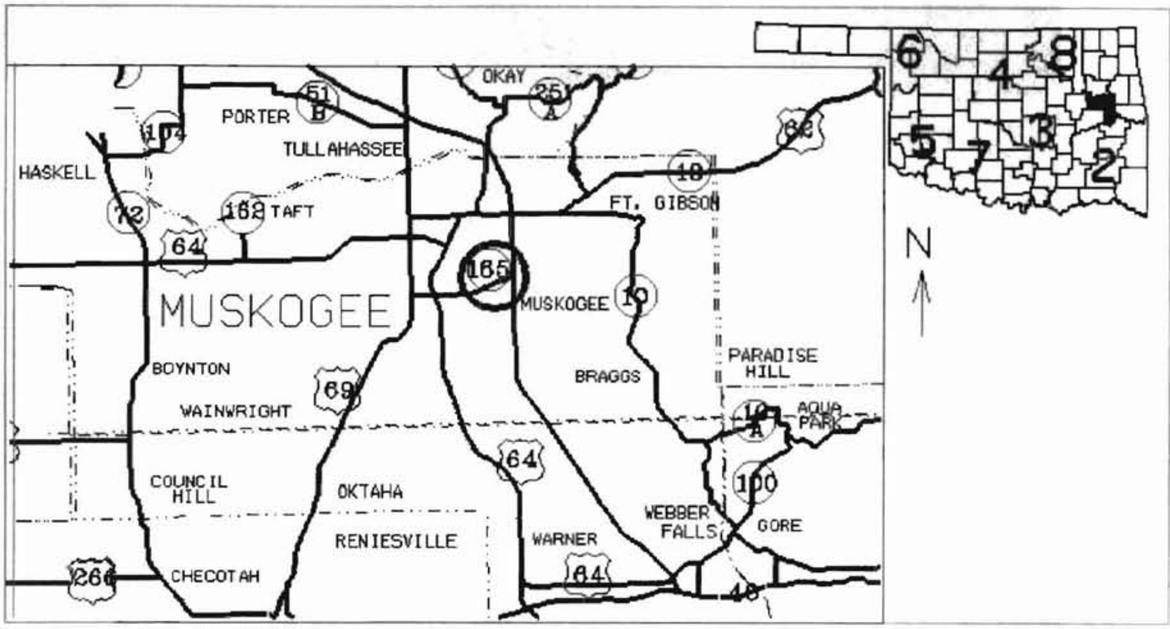


Figure A7. Location Map

Direction of travel of Survey Team: Eastbound

The Terminal Joint at the beginning was not damaged. Transverse crack spacings were 1.2 to 2.0 m. There were no spalling, punchouts, or repairs. There was some Y-cracking, but no longitudinal cracks. The construction joints were neat. The ride on the CRC was excellent. See Figure A8.

Direction of travel of Survey Team: Westbound

Transverse crack spacings were 1.5 to 2.0 m. Crack widths were 0.30 to 0.50 mm in the first and middle third sections. The last section had crack widths of 0.40 to 0.70 mm. There was light spalling at the cracks in the end third of the project and at one of the construction joints. There were no longitudinal cracks, no punchouts and no repairs. There were areas that had developed some Y-cracking, and a curved crack or two, but no longitudinal cracks and terminal joints were not damaged. The ride on the CRC was excellent. See Figure A9.

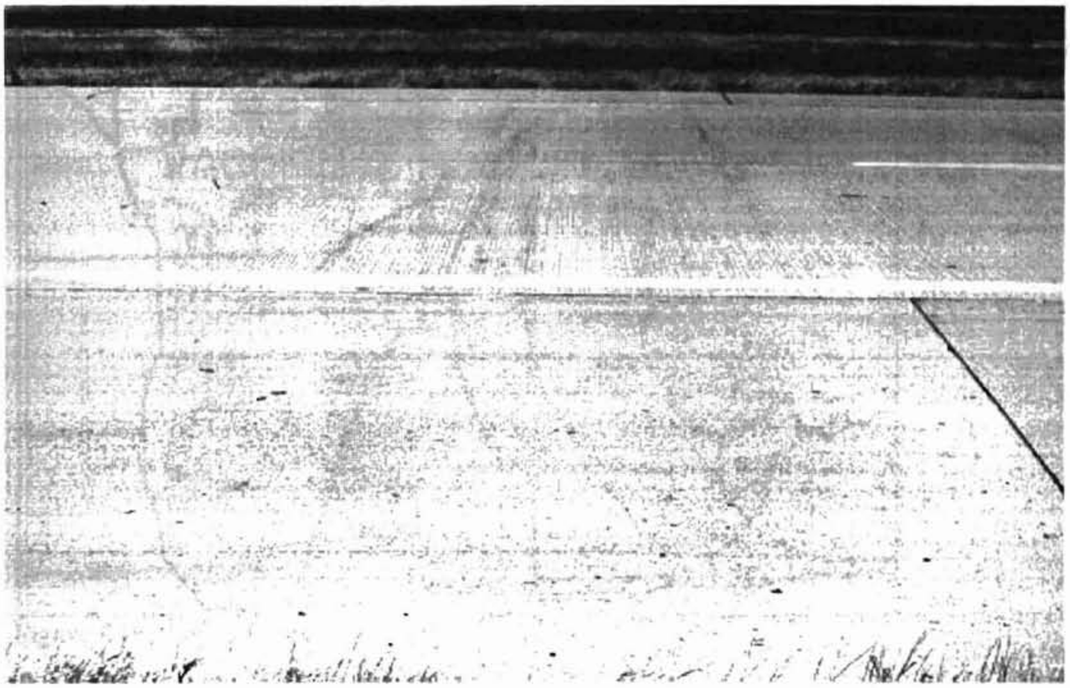


Figure A8. Typical view of MAFEGC-410(35) eastbound.

Figure A9. Typical view of MAFEGC-410(35) westbound.

CRCP.4		**Survey date:**	**July 23, 1998**
Division:	**1**	**County:**	**Muskogee**
Project #:	**MABRF-593(241)**	**Location:**	**US-69 Muskogee**

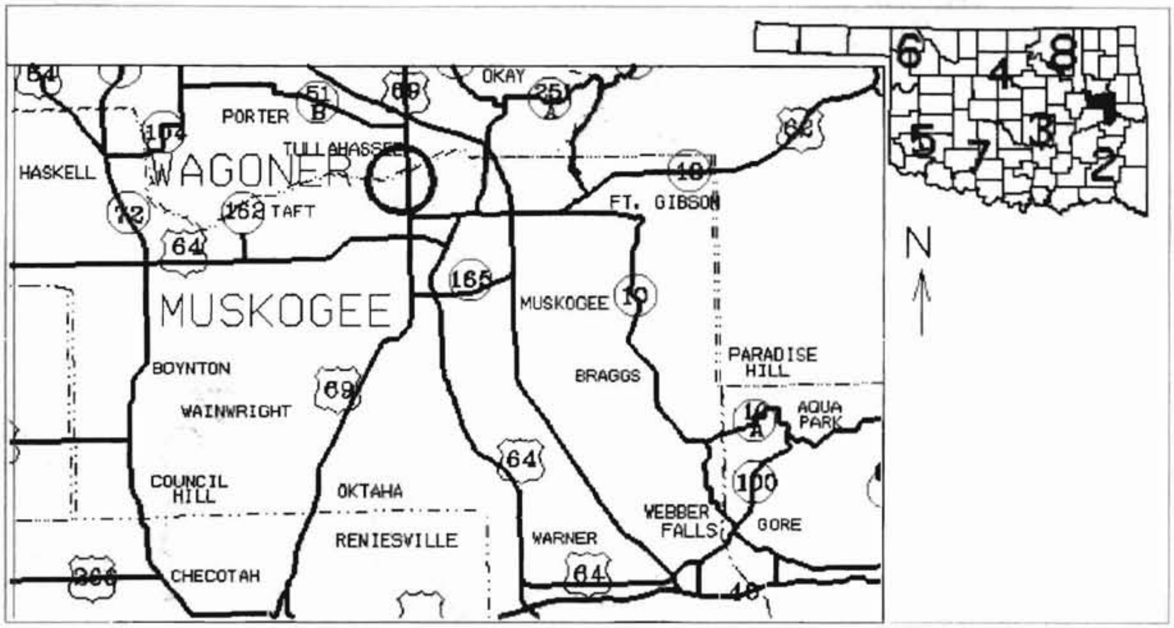


Figure A10. Location Map

Direction of travel of Survey Team: Northbound

Transverse crack spacings range from 1.5 to 2.0 m. There were some clustered cracks, but no scaling, no polished aggregate, no popouts, no blowouts and no construction joint deterioration. The terminal and construction joints were all in good shape. See Figure A11.

Direction of travel of Survey Team: Southbound

Transverse crack spacings were 1.5 to 2.0 m. There was some clustered cracking in the middle of the project. The crack had slight spalling. There were no repairs, but one punchout of about 0.2 m^2. The ride on the CRC was excellent. See Figure A12.

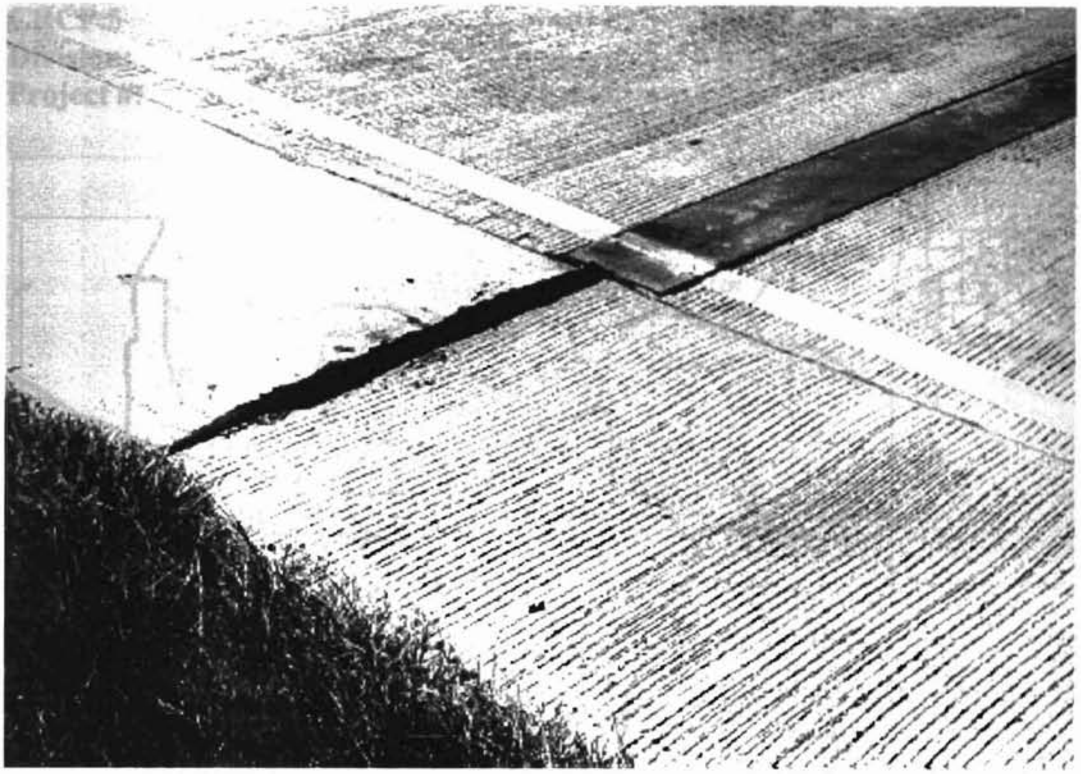


Figure A11. Steel beam at end joint.

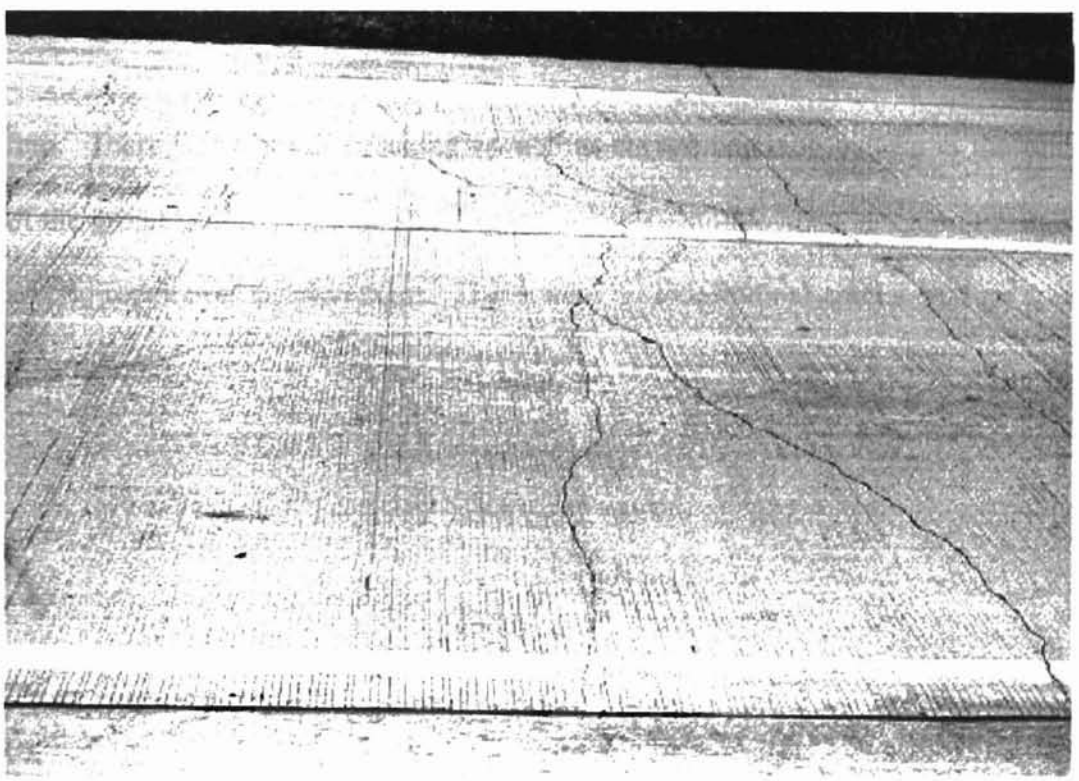


Figure A12. Typical view of MABRF-593(241)

CRCP.5		**Survey date:**	**July 23,1998**
Division:	**1**	**County:**	**Muskogee**
Project #:	**STP-404(66)**	**Location:**	**US-62**

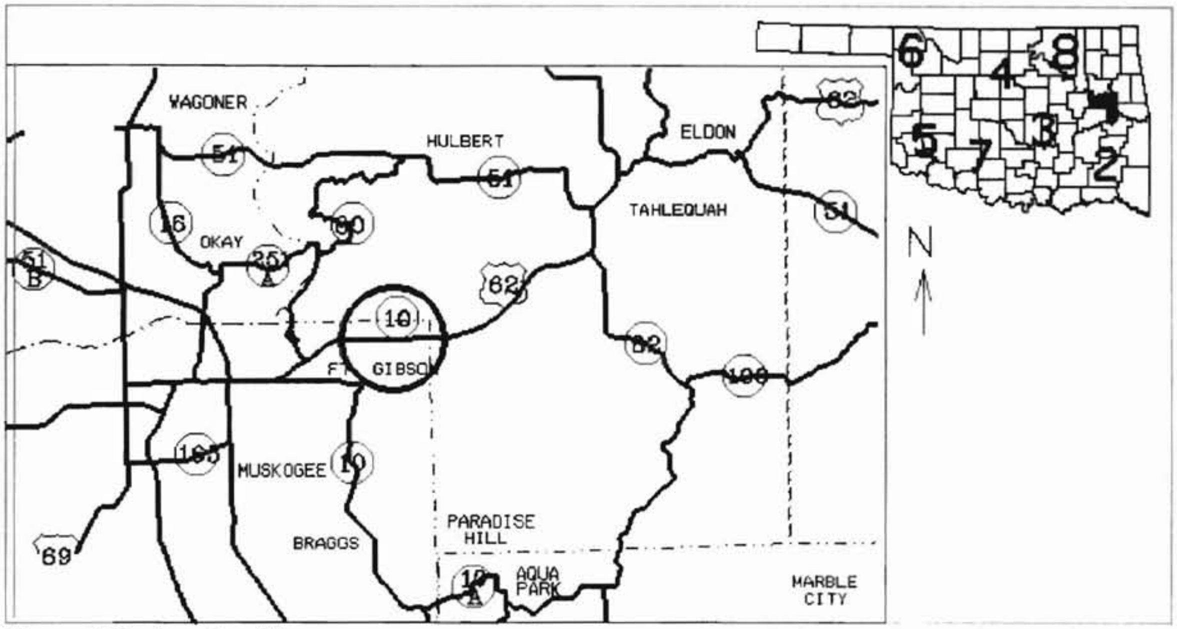


Figure A13. Location Map

Direction of travel of Survey Team: Westbound

Transverse crack spacings were 0.6 to 1.5 m. The crack widths were 0.25 to 0.60 mm. There was some Y-cracking as well as curved cracking pattern in the middle third of the project. There was no spalling at the cracks, no blowups, no popouts, no punchout and no repairs on the pavement. There were no longitudinal cracks, and no construction joint deterioration. See Figures A14 and A15.

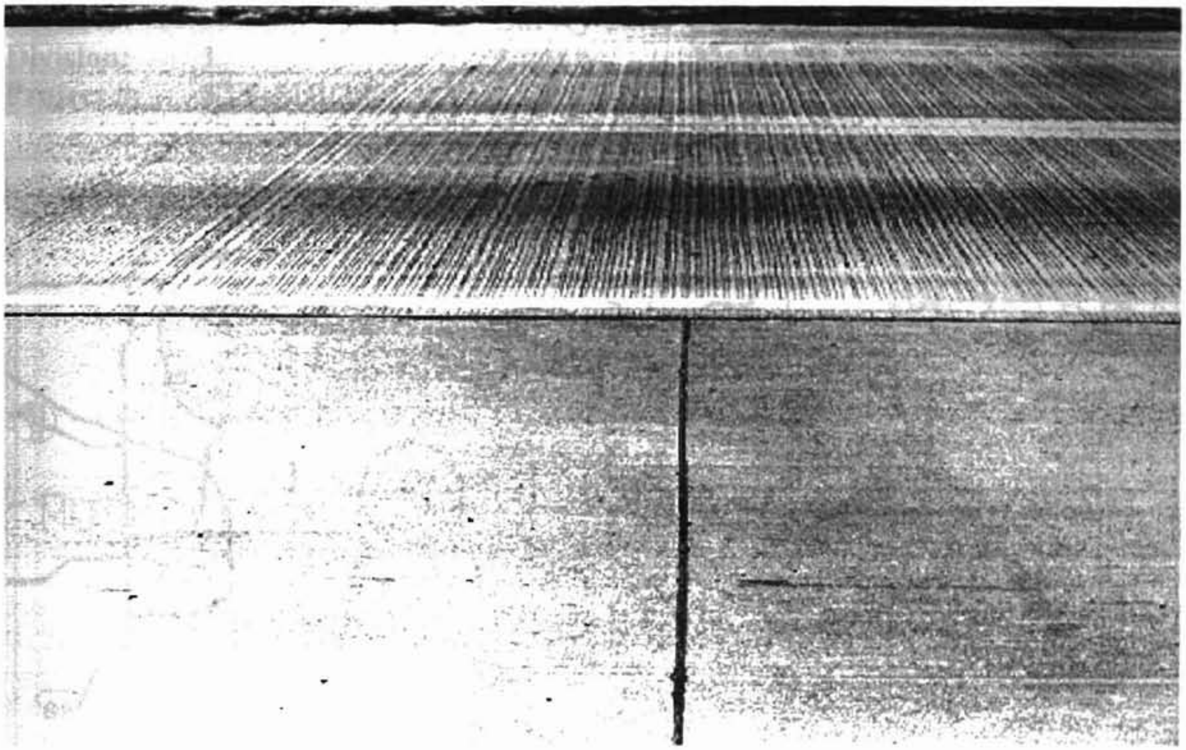


Figure A14. Typical view of STP-404(66) westbound

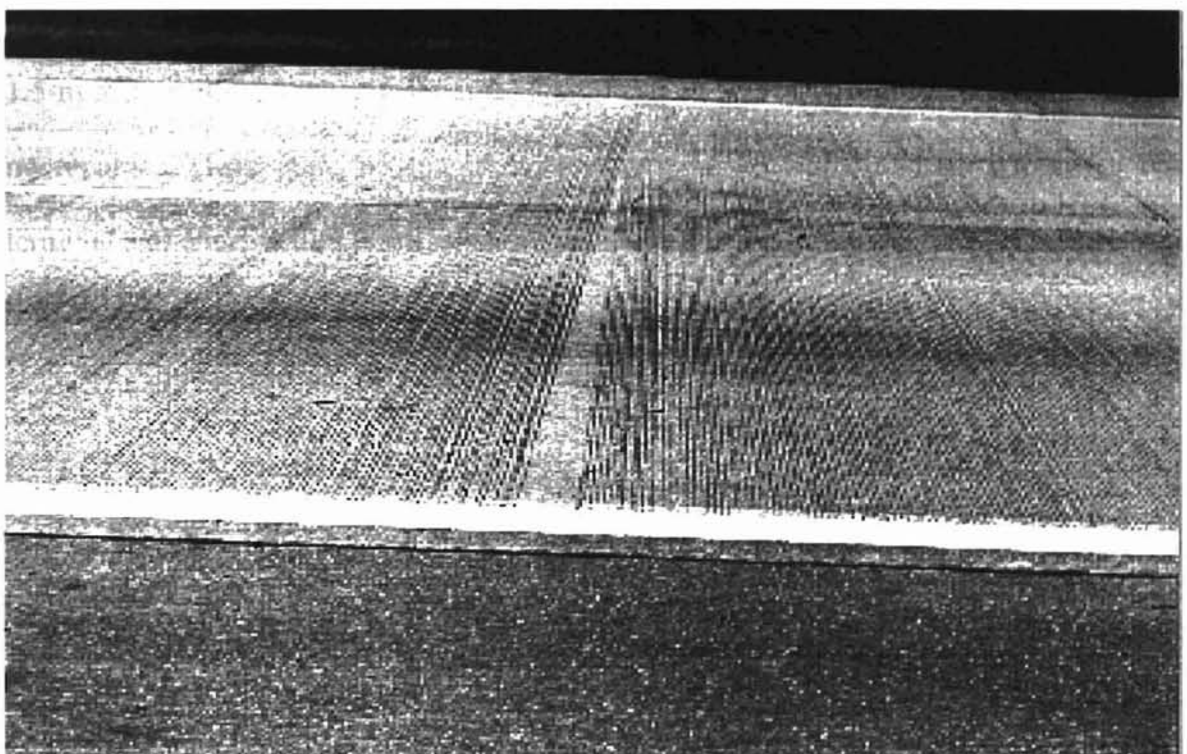


Figure A15. Typical view of pavement.

CRCP.6 | **Survey date: July 23, 1998**
Division: 1 | **County: Muskogee**
Project #: STP-51B(360) | **Location: US-62**

CRCP.6		**Survey date:**	**July 23, 1998**
Division:	**1**	**County:**	**Muskogee**
Project #:	**STP-51B(360)**	**Location:**	**US-62**

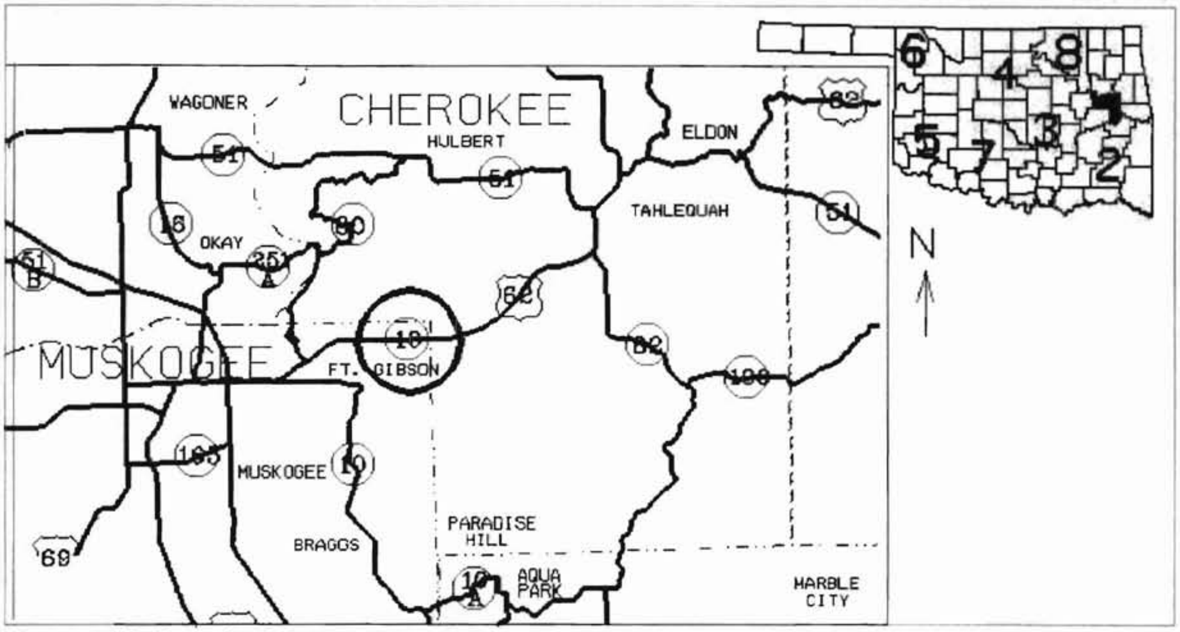


Figure A16. Location Map

Direction of travel of Survey Team: Eastbound

Transverse cracks were generally straight. Crack spacings were between 0.9 to 1.5-m and crack widths were about 0.55 mm. There was no spalling, no punchouts, and no repairs. There were no longitudinal cracks, no blowups, and no popouts. The terminal and construction joints were all good. This is a nice looking project and the feel of the ride on the CRCP was excellent. See Figure A17.

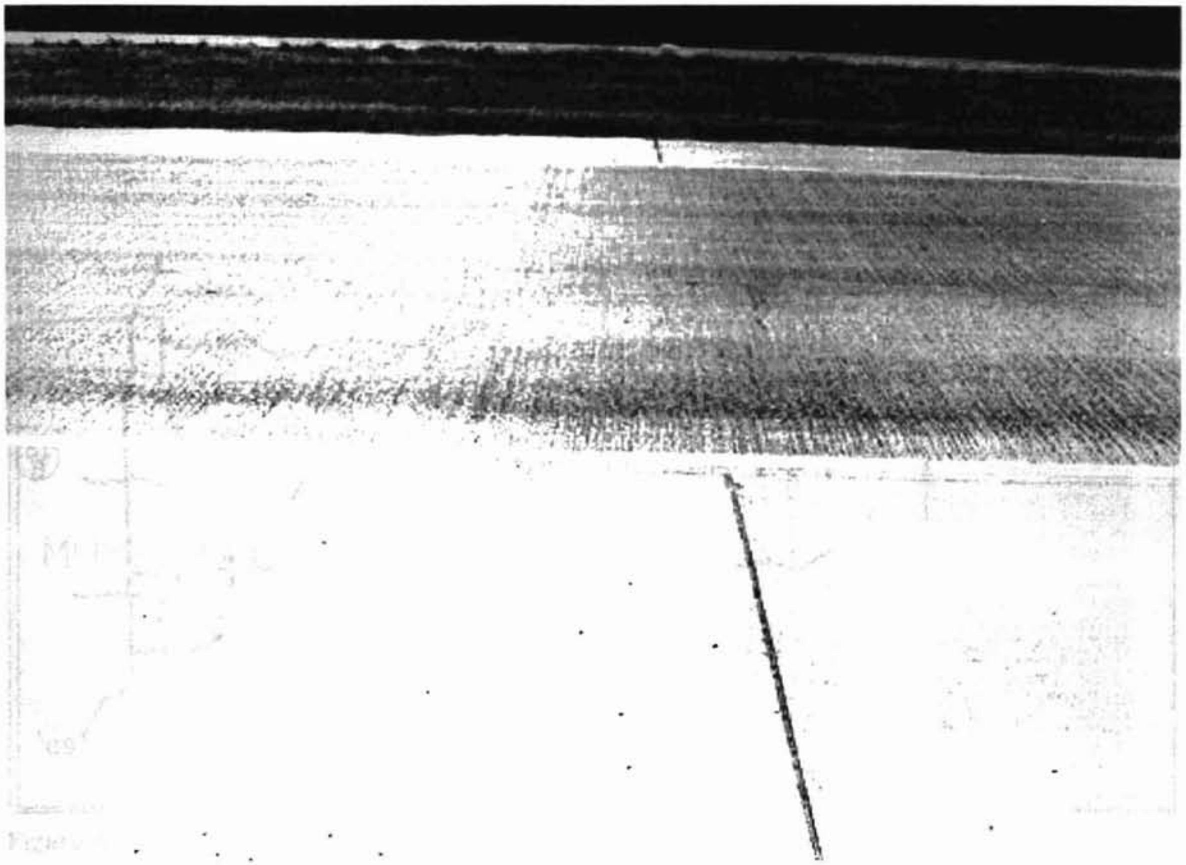


Figure A17. Typical view of STP-51B(36) eastbound

CRCP.7	**Survey date:**	**July 23, 1998**

CRCP.7		**Survey date:**	**July 23, 1998**
Division:	**1**	**County:**	**Cherokee**
Project #:	**STP-11B(334)**	**Location:**	**US-62**

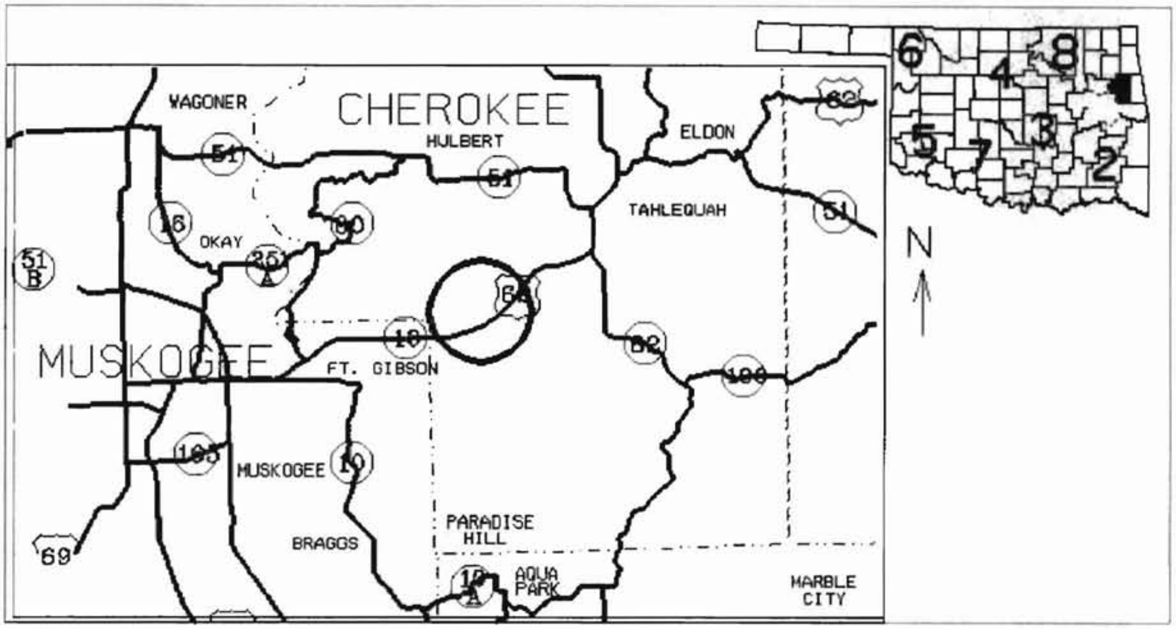


Figure A18. Location Map

Direction of travel of Survey Team: Eastbound

Generally the spacings of transverse crack were between 0.9 and 2.0 m centers. There were some Y-cracks and curved cracks. The crack widths were small. No longitudinal cracks were observed. There was no construction joint deterioration. There was no spalling, no punchouts, and no repairs. The terminal joints were both good and the ride was excellent. Figure A19 is a typical view of the condition of the pavement.

Direction of travel of Survey Team: Westbound

Transverse crack spacings were 1.2 to 2.0 m centers. The crack widths were 0.25 to 0.50 mm for the whole length. Some cracks Y-cracks and curved cracks. There were no longitudinal cracks and no construction joint deterioration. There was no spalling, no punchouts, and no repairs. Although the filler has extruded from the end joints, the terminal joints were in good shape. See Figure A20.

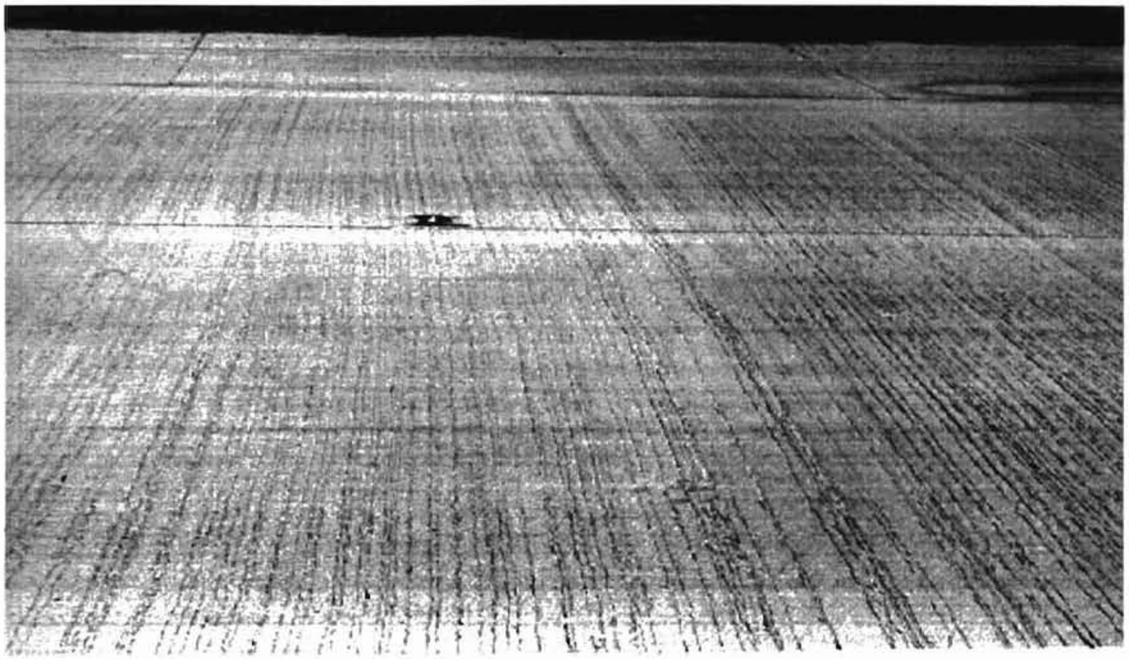


Figure A19. Typical view of CRC on STP-11B(334)

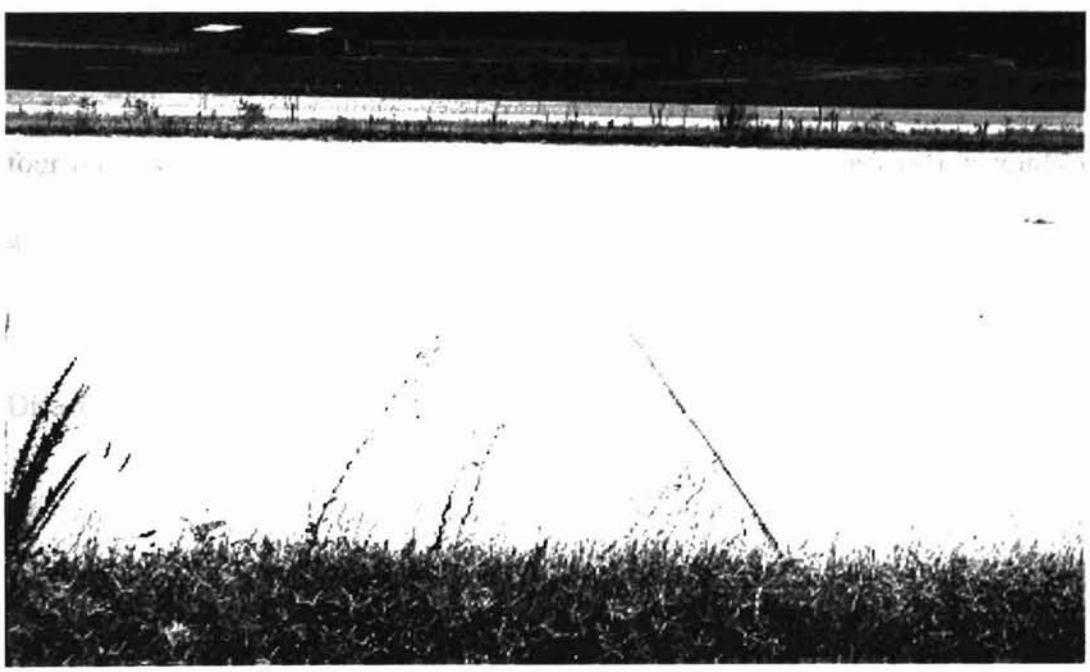


Figure A20. Typical view of STP-11B(334) westbound

CRCP.8		**Survey date:**	**July 23, 1998**
Division:	**1**	**County:**	**Sequoyah**
Project #:	**IR-40-6(220)**	**Location:**	**I-40 east of Vian**

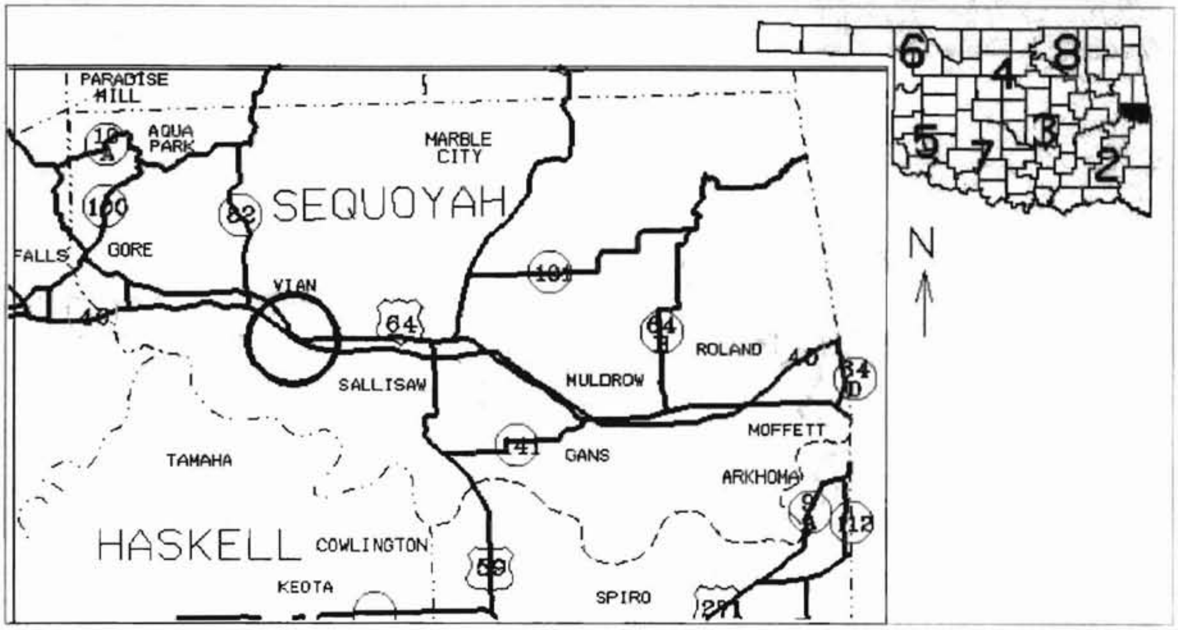


Figure A21. Location Map

Direction of travel of Survey Team: Eastbound

Transverse crack spacings were 1.2 to 2.0 m centers. The crack widths were 0.20 to 0.70 mm. There was no spalling. No longitudinal cracks were seen. There were about four areas with patching totaling 18 m^2. The terminal and construction joints were all good. The ride on the CRC was excellent. See Figure A22.

Direction of travel of Survey Team: Westbound

Generally the spacings of transverse cracks were between 1.5 and 2.0 m centers for the whole of this direction. Crack widths were about 0.25 to 0.50 mm. There is one longitudinal crack, about 50 m long, around the middle of the project. There was spalling, punchout, and repairs. Some construction joints had punchout and repairs. The sum of the area of patches, including those at the joints, was about 20 m^2. Faulting had occurred at some joints. See Figure A23.

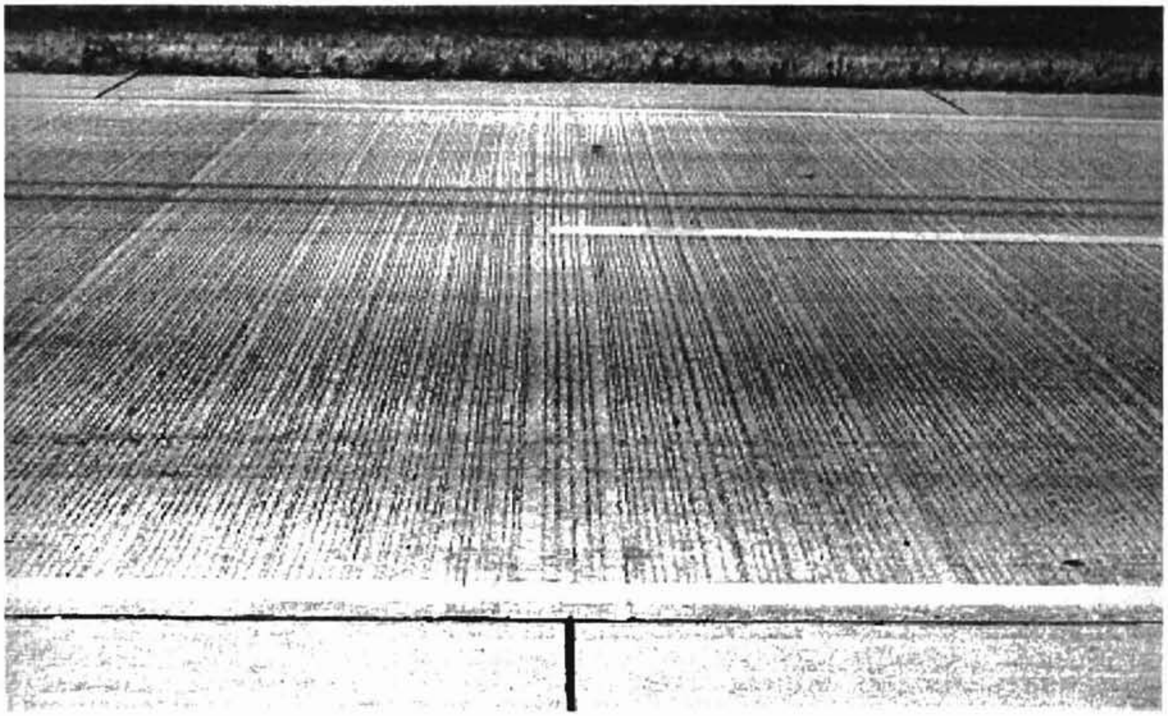


Figure A22. Typical view of IR-40-6(220) eastbound

Figure A23. Patch next to repair westbound

CRCP.9		**Survey date:**	**July 23, 1998**
Division:	**1**	**County:**	**Sequoyah**
Project #:	**IR-40-6(222)301**	**Location:**	**I-40 east of Vian**

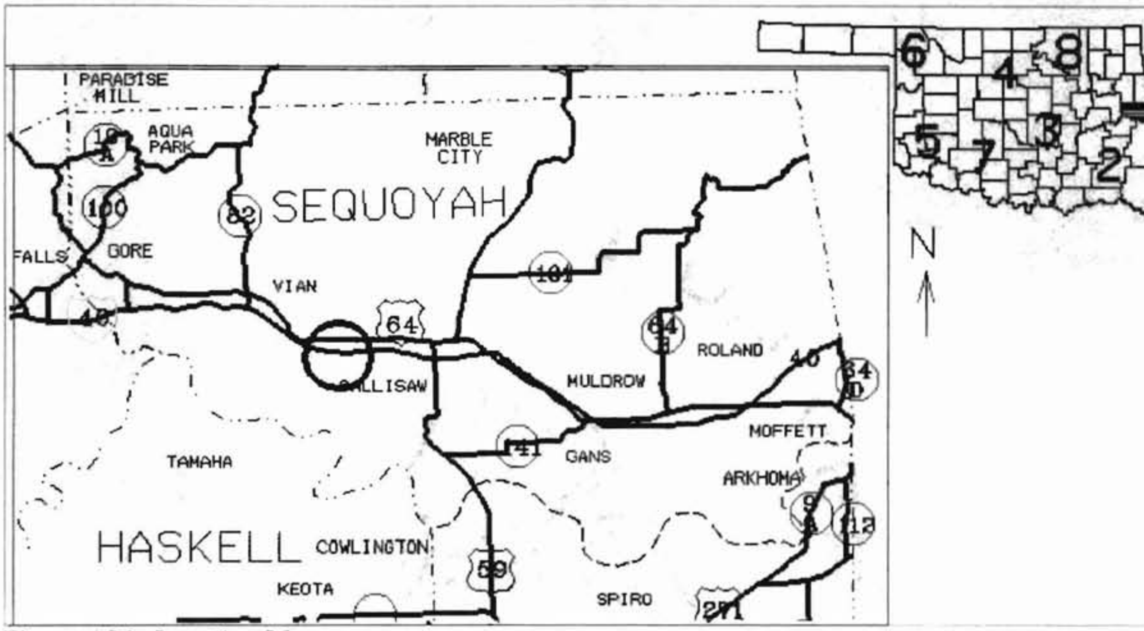


Figure A24. Location Map

Direction of travel of Survey Team: Eastbound

Transverse crack spacings range from 0.6 to 1.5 m. The crack widths were 0.30 to 0.60 mm in the first third of the project and 0.20 to 0.50 mm in the middle third. There were no clustering of cracks, no longitudinal cracks and no punchouts. There was no spalling. The terminal and construction joints had repairs totaling 0.5 m^2 in area. There was spalling at the east end wide flange. The ride on the CRC was excellent. See Figures A25 and A26 for an underdrain outlet and typical condition of the pavement.

Figure A25. Outlet of pavement underdrain

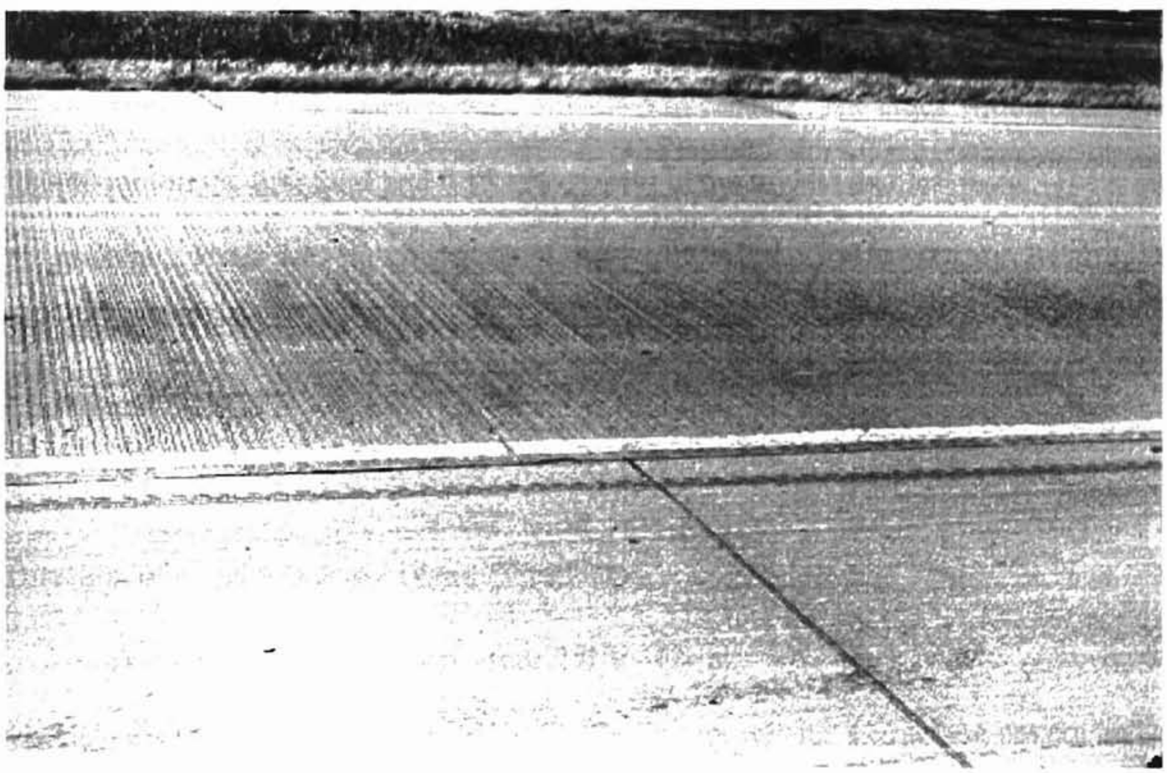


Figure A26. Typical view of IR-40-6(222)

CRCP.10		**Survey date:**	**July 23, 1998**
Division:	**1**	**County:**	**Sequoyah**
Project #:	**IR-40-6(221)**	**Location:**	**I-40 east of Sallisaw**

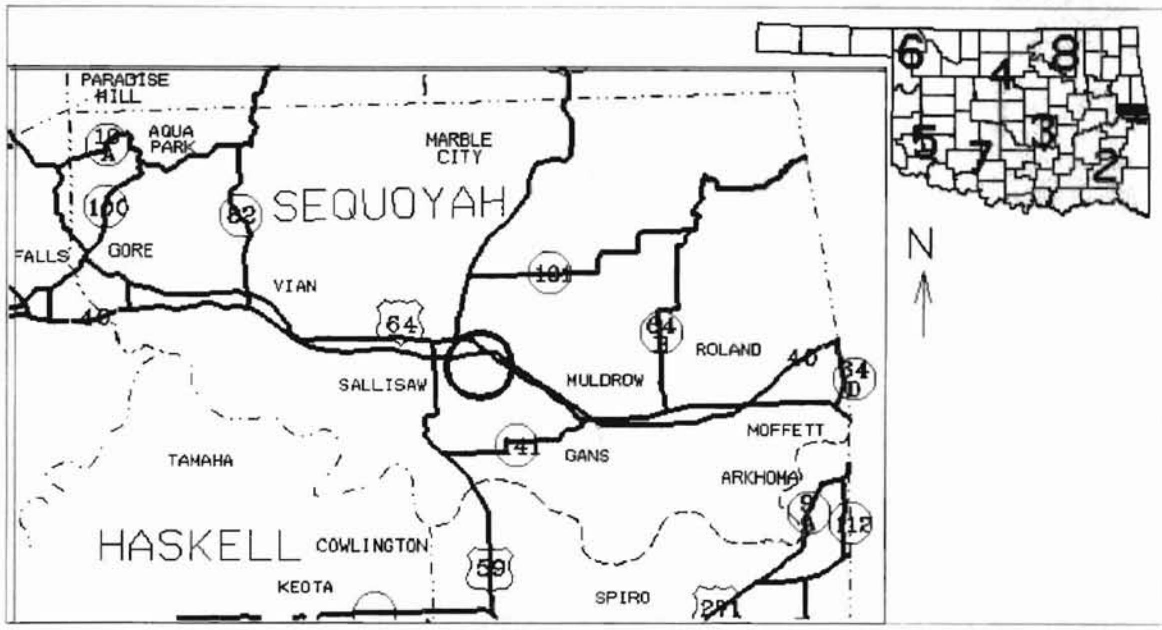


Figure A27. Location Map

Direction of travel of Survey Team: Eastbound

Transverse crack spacings were 3.0 to 4.5 m centers. The crack widths were 0.20 to 0.40 mm in the first third and 0.15 to 0.30 mm in the middle and last third. There was no spalling. There was no clustering of cracks observed. There were no longitudinal cracks, and no punchouts. The terminal and construction joints were all in good shape. The ride on the CRCP was excellent. See Figure A28.

Direction of travel of Survey Team: Westbound

Transverse crack spacings were 3.0 to 4.5 m. The crack widths were hardly visible – about 0.10 mm for most of the CRCP. There was no Y-cracking pattern and no spalling at the cracks. There were no clustering of cracks observed, no longitudinal cracks, and no punchouts. The terminal and construction joints were all in good shape. The pavement looks good and the ride was excellent. See Figure A29.

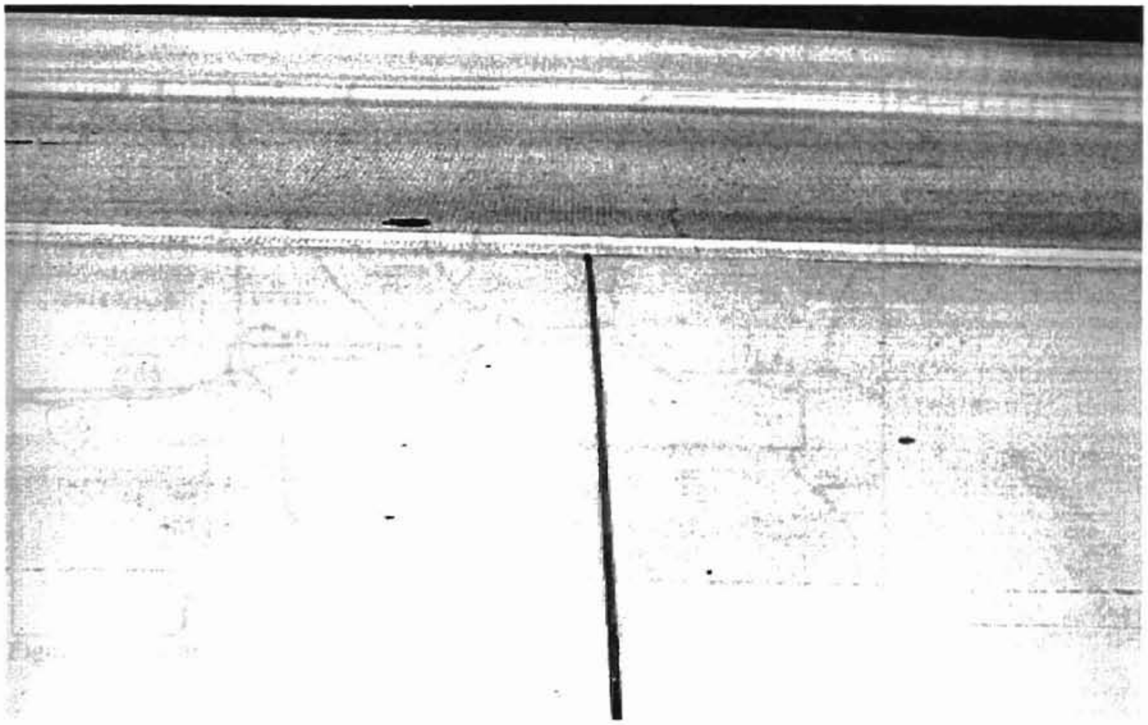


Figure A28. Typical view of IM-40-6(221) eastbound.

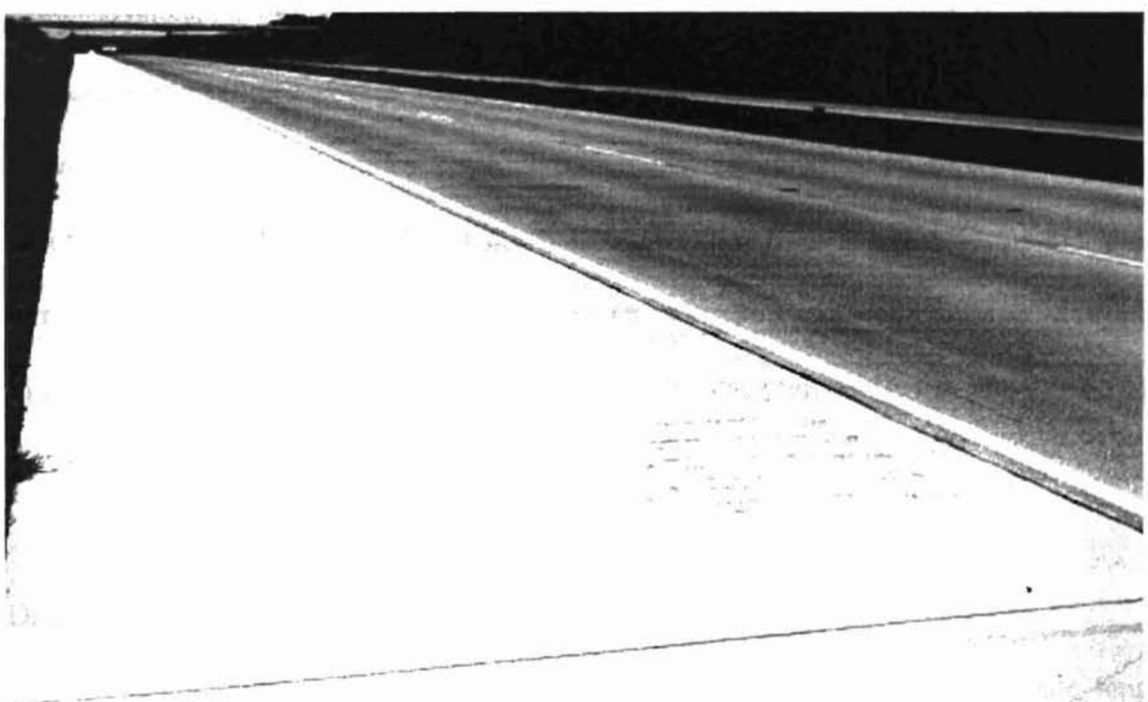


Figure A29. Typical view of IM-40-6(221) westbound.

CRCP.11 | | **Survey date:** | **July 23, 1998**

Division:	**1**	**County:**	**Muskogee**
Project #:	**I-40-6(86)**	**Location:**	**I-40 near Warner**

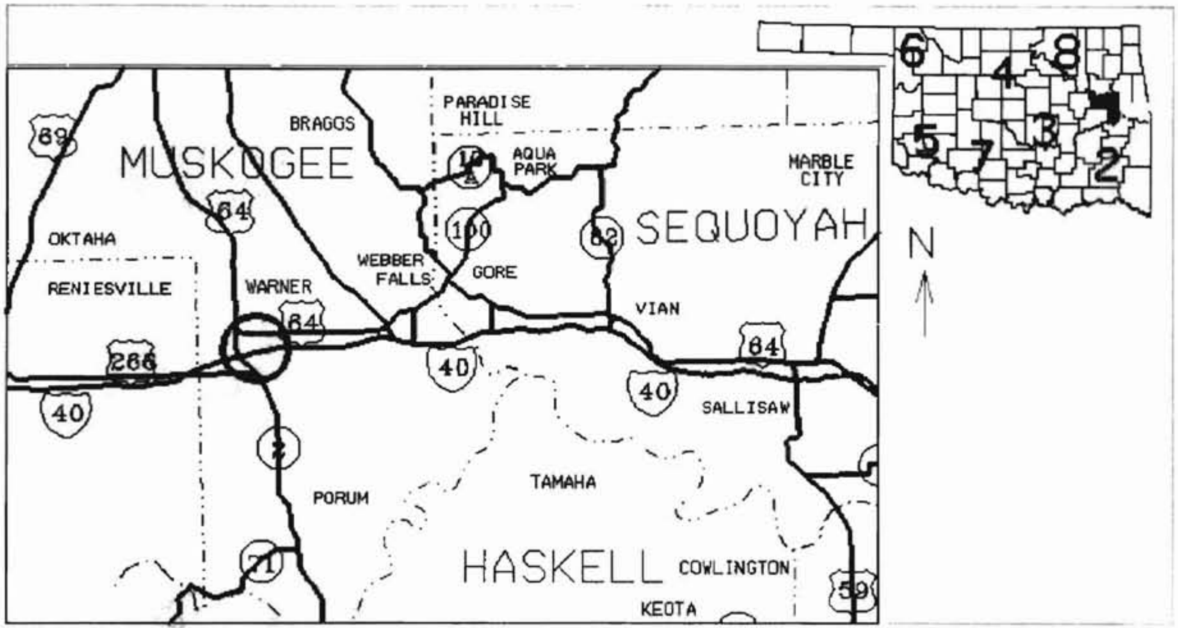


Figure A30. Location Map

Direction of travel of Survey Team: Eastbound

Transverse crack spacings were 0.6 to 1.2 m for the initial third, 0.3 to 1.2 m for the rest of the project. Crack widths were about 0.80 to 1.40 mm for the whole length. There were longitudinal cracks, spalling, punchouts, and repairs. There were, in general, more than ten patches per mile for the first third, less than five per mile for the middle third, and bigger patches in the last third – some as big as 4.5 m x 3.6 m (lane width). See Figure A31. Despite the numerous places of repair and punchouts, the ride on the CRC was good.

Direction of travel of Survey Team: Westbound

Generally transverse crack spacings were 0.6 to 1.5 m for the whole length. Crack widths were about 0.60 to 1.50 mm. There were longitudinal cracks, some about

10 m long. There was spalling, punchouts, and repairs. There were, in general, more than six patches per mile. Some patches were as big as 10 m by 3.6 m lane, others as much as about one-fifth km long by the 3.6 m lane width. See Figure A32. The numerous repairs and punchouts did not affect the smoothness of the ride

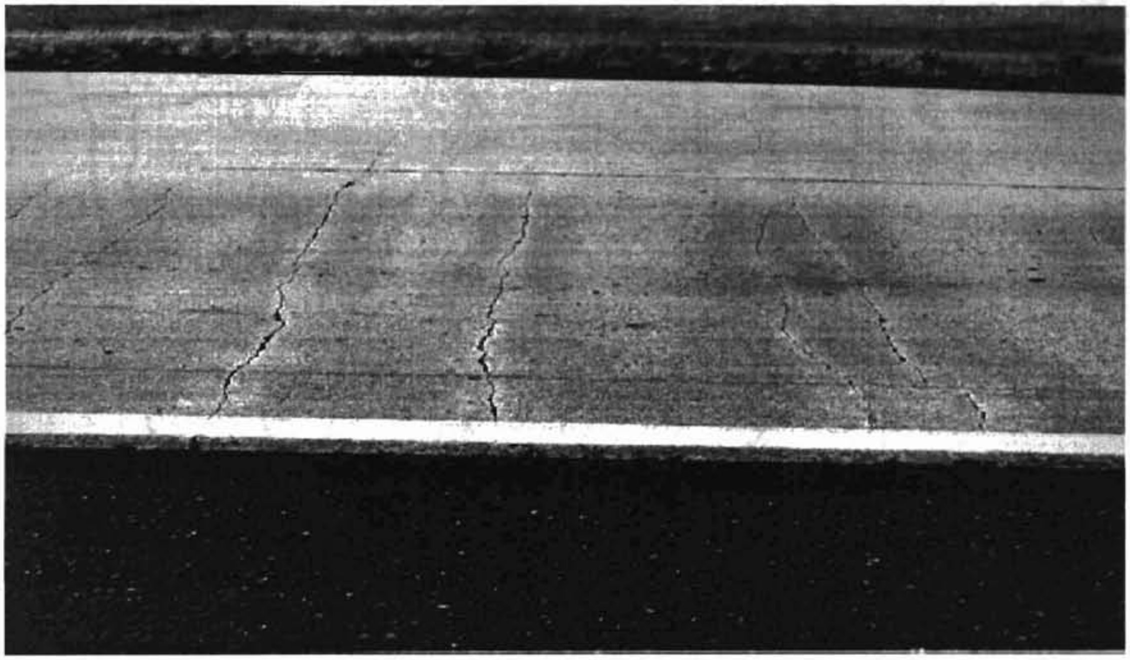


Figure A31. Wide transverse crack widths on I-40-6(86) eastbound.

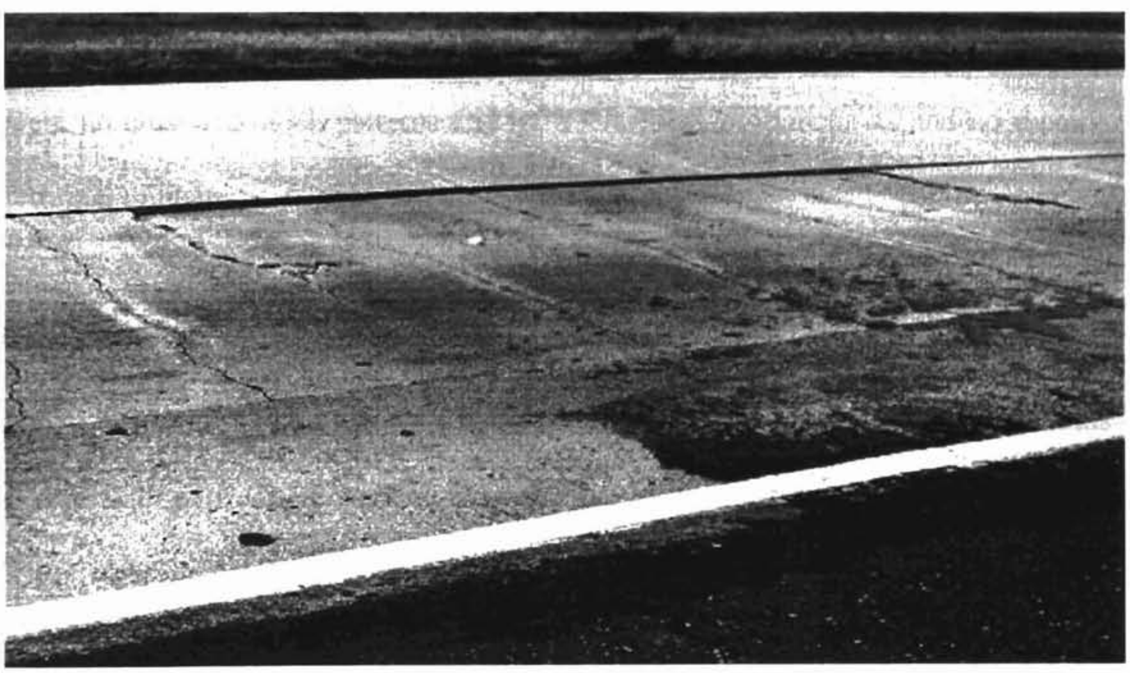


Figure A32. Wide crack widths and faulting westbound.

CRCP.12		**Survey date:**	**July 23 and 24, 1998**
Division:	**2**	**County:**	**Pittsburg**
Project #:	**MAF-186(180)**	**Location:**	**US-69**

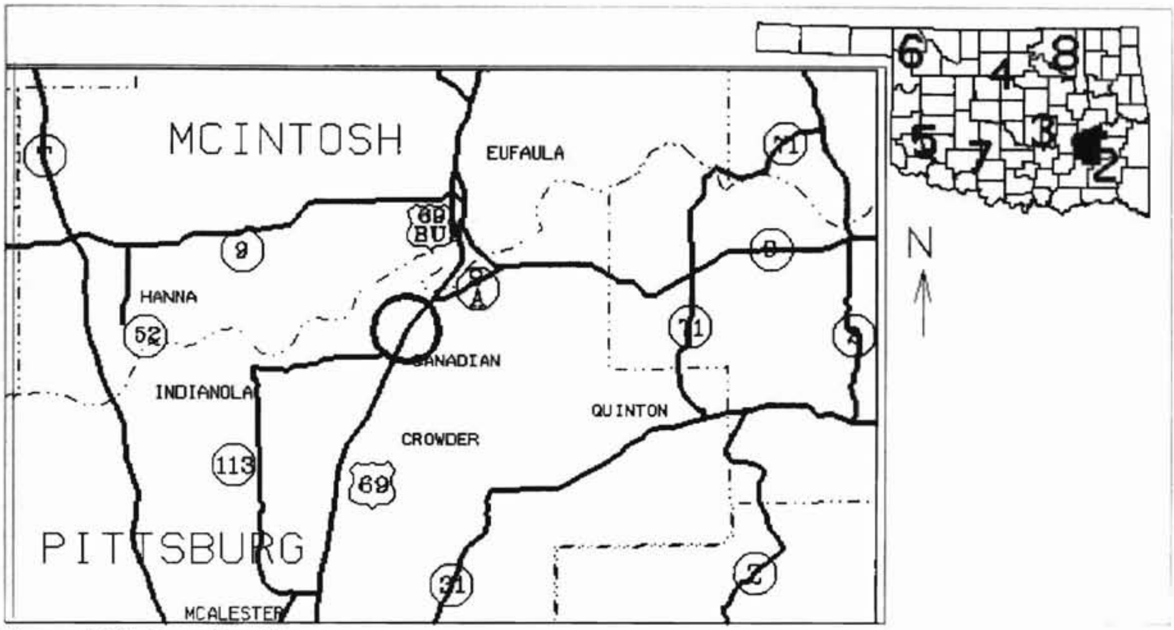


Figure A33. Location Map

Direction of travel of Survey Team: Northbound

There were no longitudinal cracks in the pavement. The transverse crack spacings range from 0.3 to 1.2 m and the crack widths were of the order of 0.10 to 0.30 mm. The crack widths were generally tighter than those in the southbound lanes. There were no clustered crack patterns and no Y-cracking, no punchouts and no repairs. The terminal joints were in good condition. See Figure A34.

Direction of travel of Survey Team: Southbound

Transverse crack spacings were 1.5 to 2.0 m for this direction. Crack widths were 0.20 to 0.40 mm. There were no clustered cracks, no spalling, punchouts, and no repairs. There were no longitudinal cracks. See Figure A35.

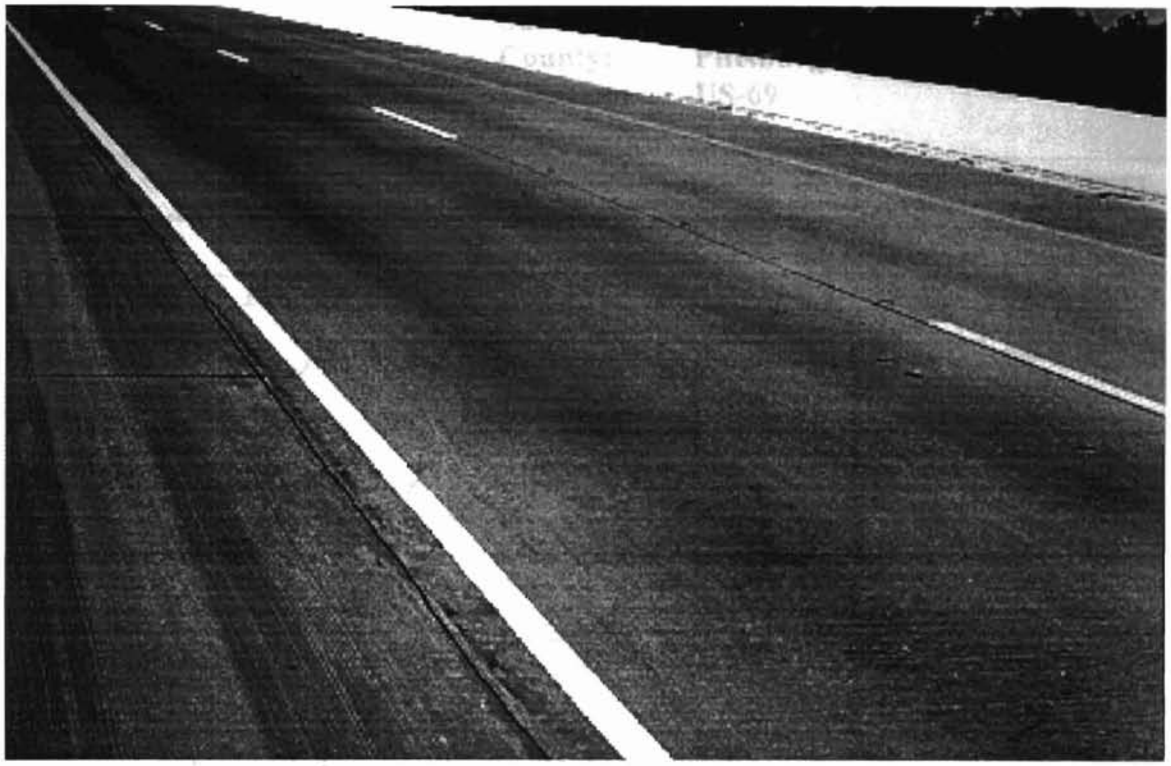


Figure A34. Typical view of MAF-186(180) northbound.

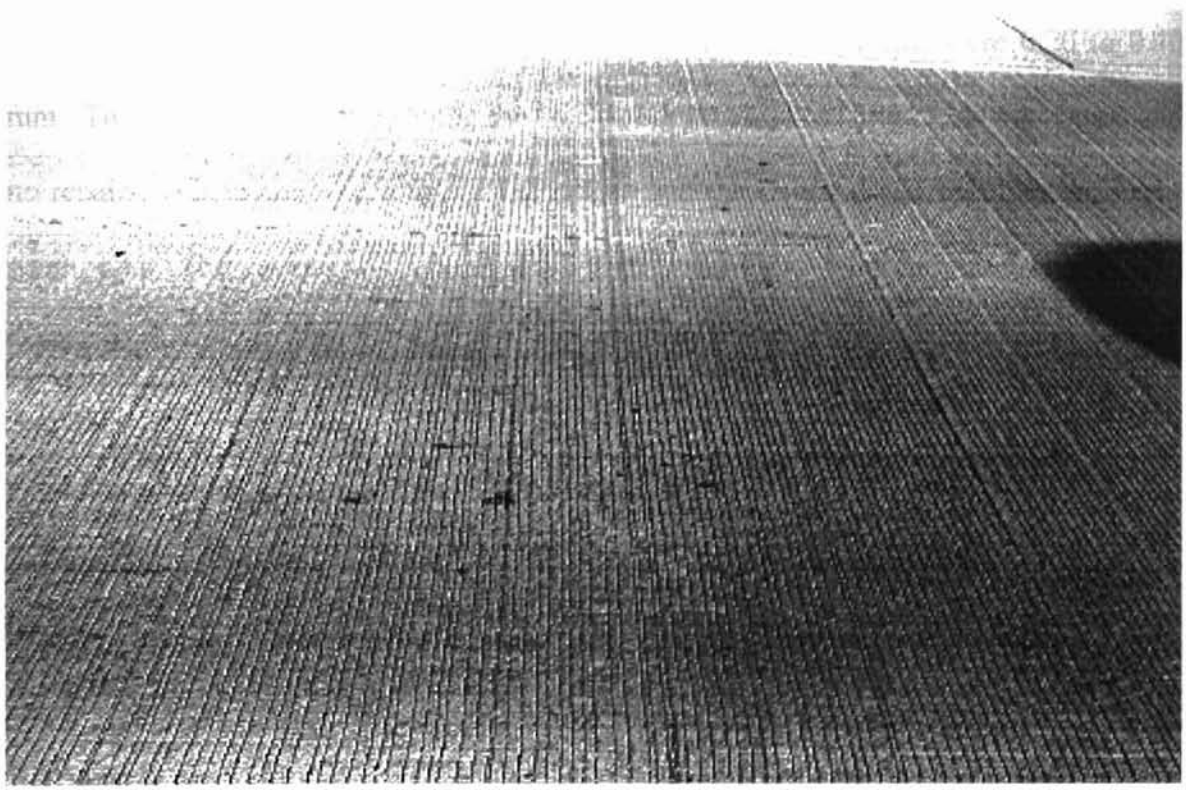


Figure A35. Typical view of MAF-186-(180) southbound.

CRCP.13		**Survey date:**	**July 23 and 24, 1998**
Division:	**2**	**County:**	**Pittsburg**
Project #:	**DPIY-204(001)**	**Location:**	**US-69**

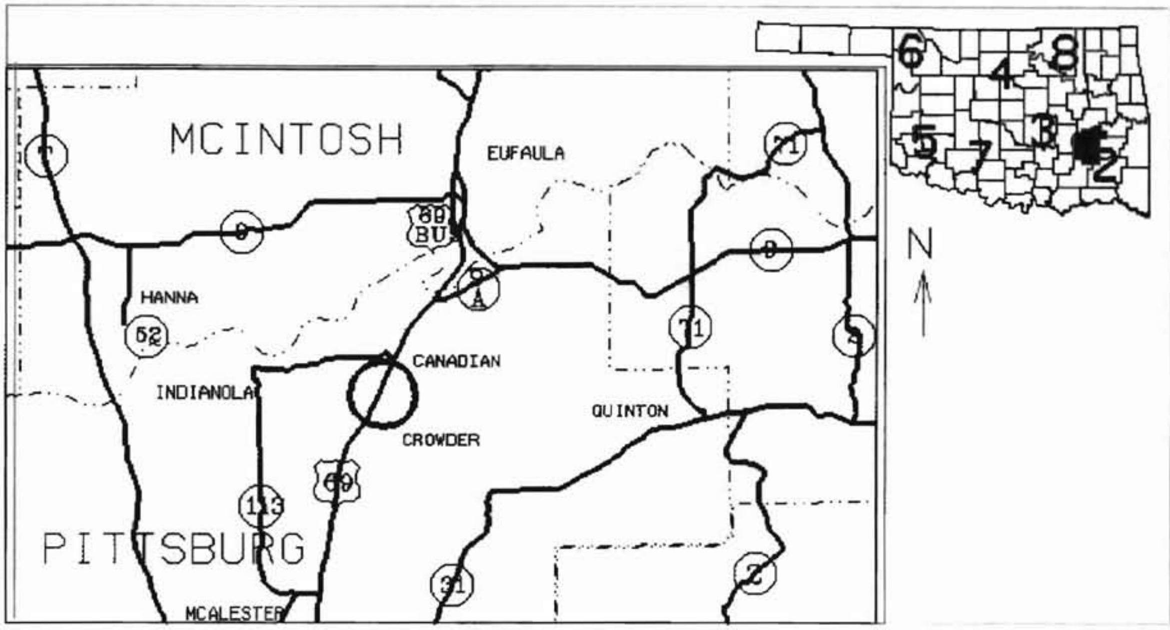


Figure A36. Location Map

Direction of travel of Survey Team: Northbound

Transverse crack spacings were 1.8 to 2.0 m. Crack widths were 0.20 to 0.40 mm. There was light spalling along the cracks, but no clustered cracks, no punchouts and no repairs. There were no longitudinal cracks and the terminal and construction joints were good. The pavement is one of those with underdrain. A drain outlet is shown in Figure A37.

Direction of travel of Survey Team: Southbound

Transverse crack spacings were 1.5 to 2.0 m for this direction. Crack widths were 0.30 to 0.50 mm. There were no clustered cracks, no spalling, but one 0.1 m^2 punchouts. See Figure A38. There were no longitudinal cracks, no blowups, no popouts, no scaling and no construction joint deterioration.

Figure A37. Exit of pavement underdrain northbound.

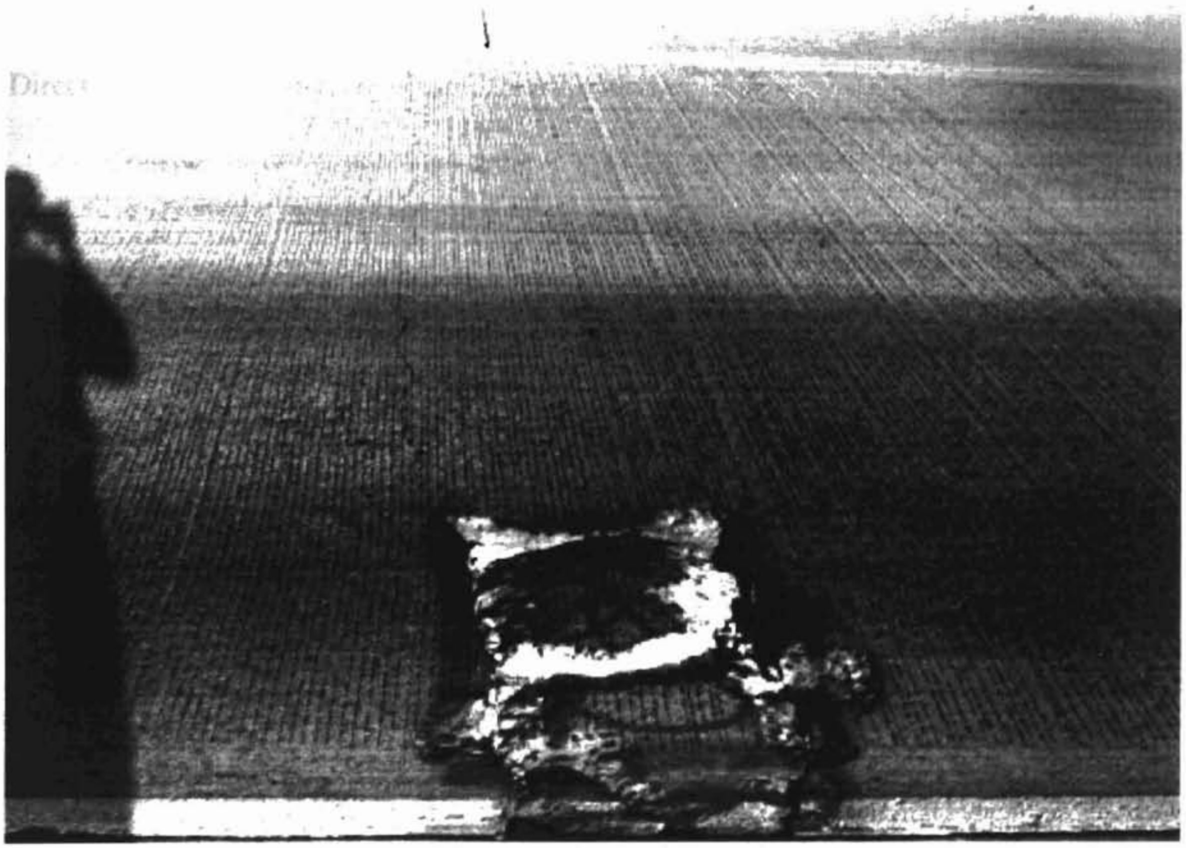


Figure A38. A punchout in southbound DPIY-204(001).

CRCP.14		**Survey date:**	**July 23 and 24, 1998**
Division:	**2**	**County:**	**Pittsburg**
Project #:	**MAF-186(185)**	**Location:**	**US-69 north of McAlester**

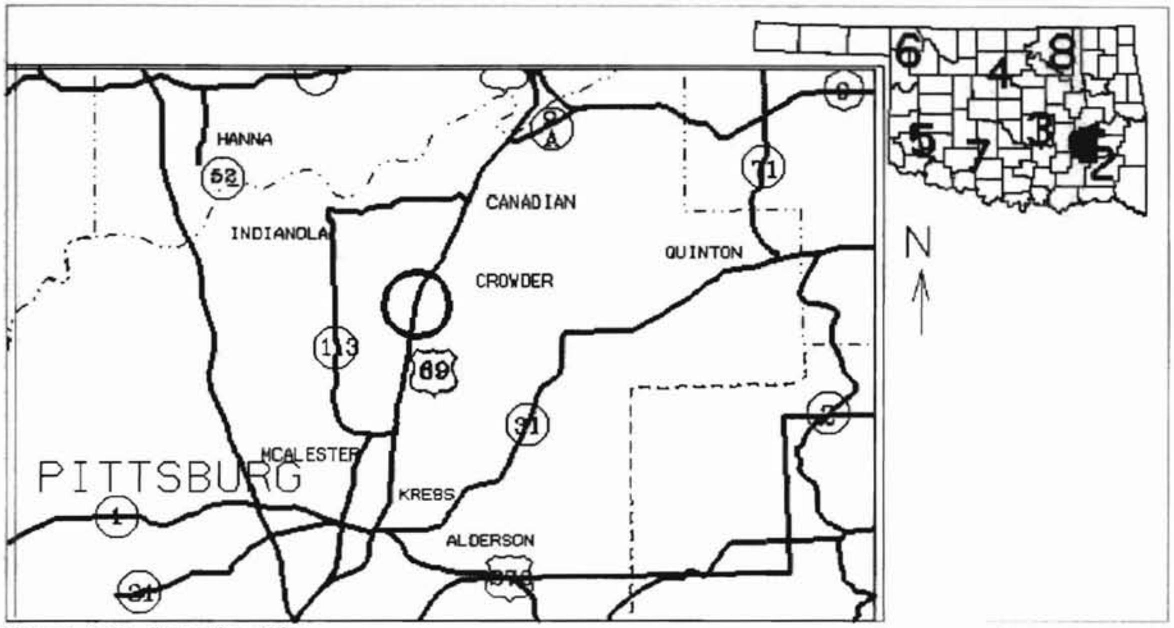


Figure A39. Location Map

Direction of travel of Survey Team: Northbound

Transverse crack spacings were 1.2 to 2.0 m. Crack widths between 0.20 and 0.90 mm increasing northwards. There were no clustering, no Y-cracks, no longitudinal cracks, no punchouts and no repairs. Grinding has been done at some construction joints and this may be at the time of construction. See Figure A40.

Direction of travel of Survey Team: Southbound

Transverse crack spacings were 0.9 to 1.5 m for this direction. Crack widths were 0.30 to 0.60 mm. There were no clustered cracks, no Y-cracks, no spalling, no punchouts and no repairs. There were no longitudinal cracks. See Figure A41. The terminal and construction joints were all good. The ride on the CRC was excellent.

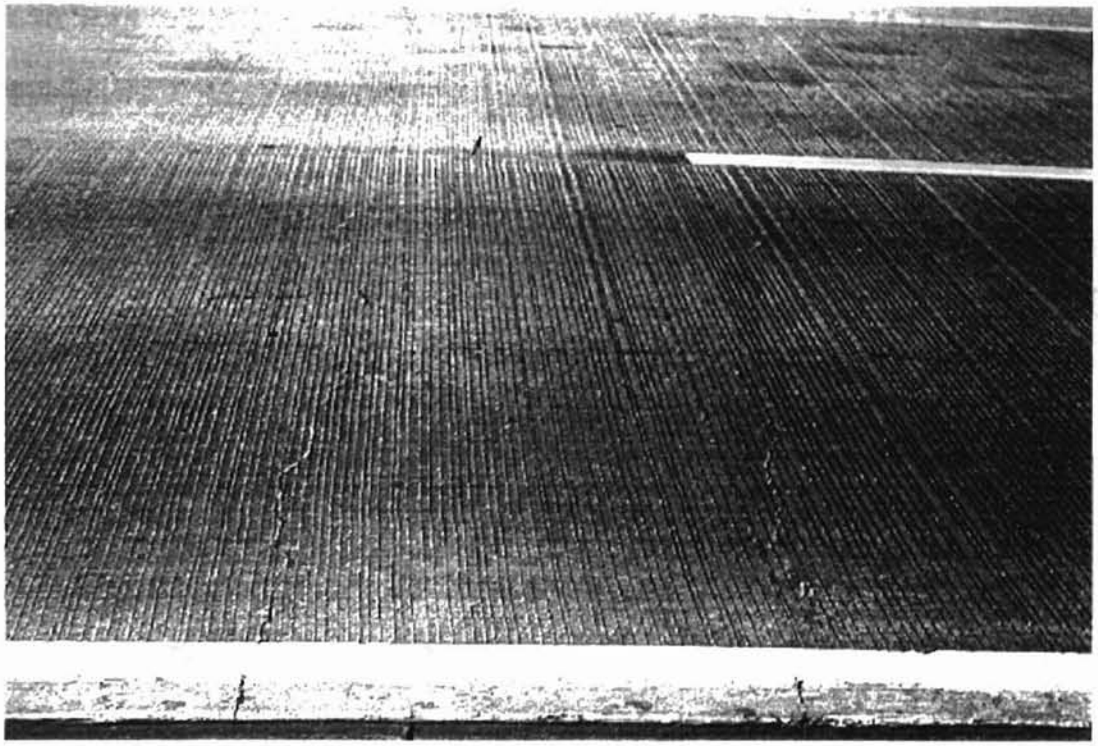


Figure A40. Typical view of MAF-186(185) northbound.

Figure A41. Typical pavement condition on MAF-186(185) southbound.

CRCP.15		**Survey date:**	**July 23 and 24, 1998**
Division:	**2**	**County:**	**Pittsburg**
Project #:	**MAF-186(183)**	**Location:**	**US-69**

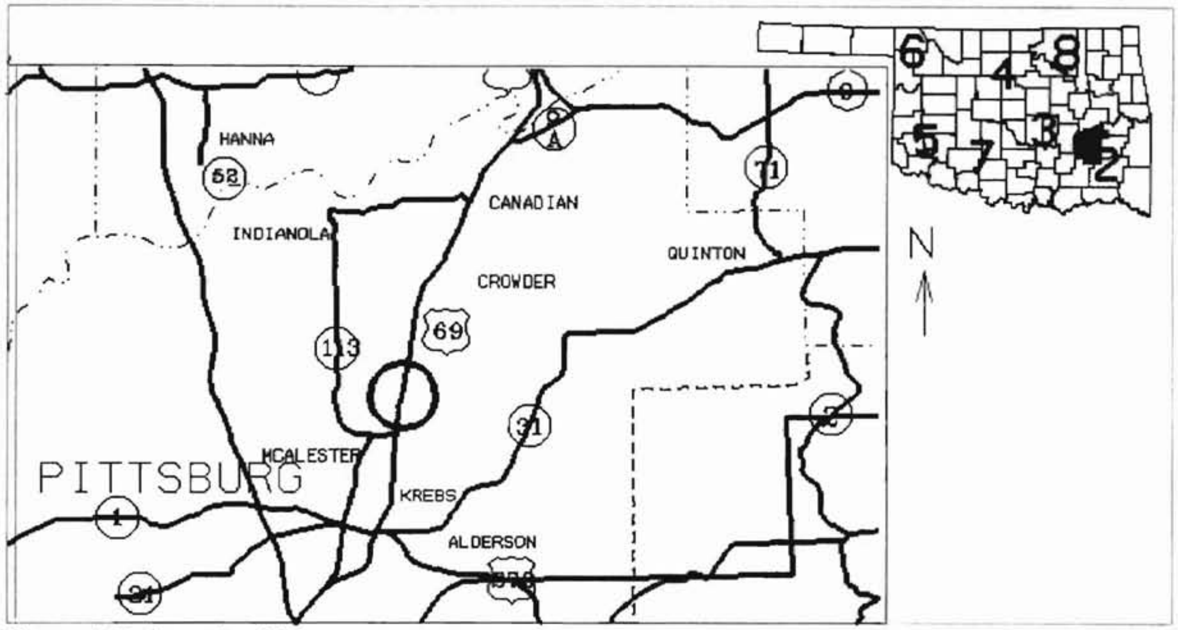


Figure A42. Location Map

Direction of travel of Survey Team: Northbound

Transverse cracks spacings were about 0.6 m in the middle third of the project and range from 1.5 to 2.0 m for the rest of the pavement with light spalling at some cracks. Crack widths were of the order of 0.20 to 0.60 mm. There were some curved cracks. The on/off ramps to the projects were all in good condition. See Figure A43.

Direction of travel of Survey Team: Southbound

Transverse crack spacings were 1.5 to 2.0 m for this direction. Crack widths were 0.20 to 0.60 mm. There were no clustered cracks, no Y-cracking, no spalling, no punchouts and no repairs. There were no longitudinal cracks. The terminal and construction joints were all good. The ride on the CRC was excellent. See Figure A44.

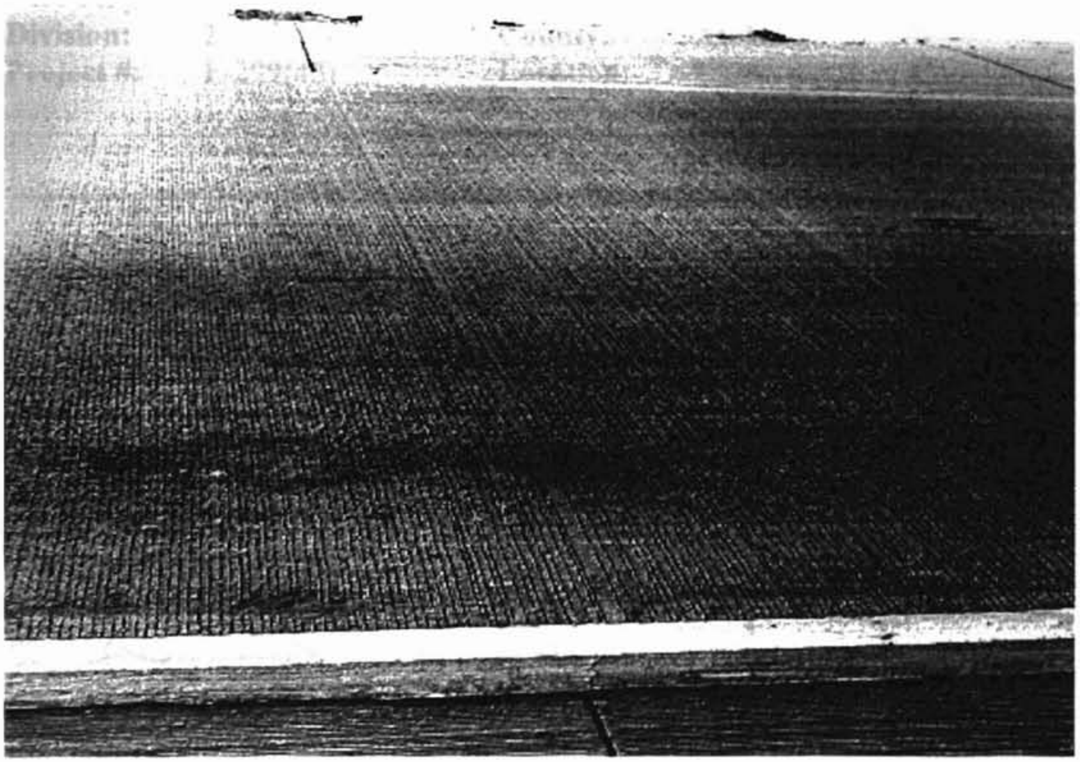


Figure A43. Typical pavement condition on MAF-186(183).

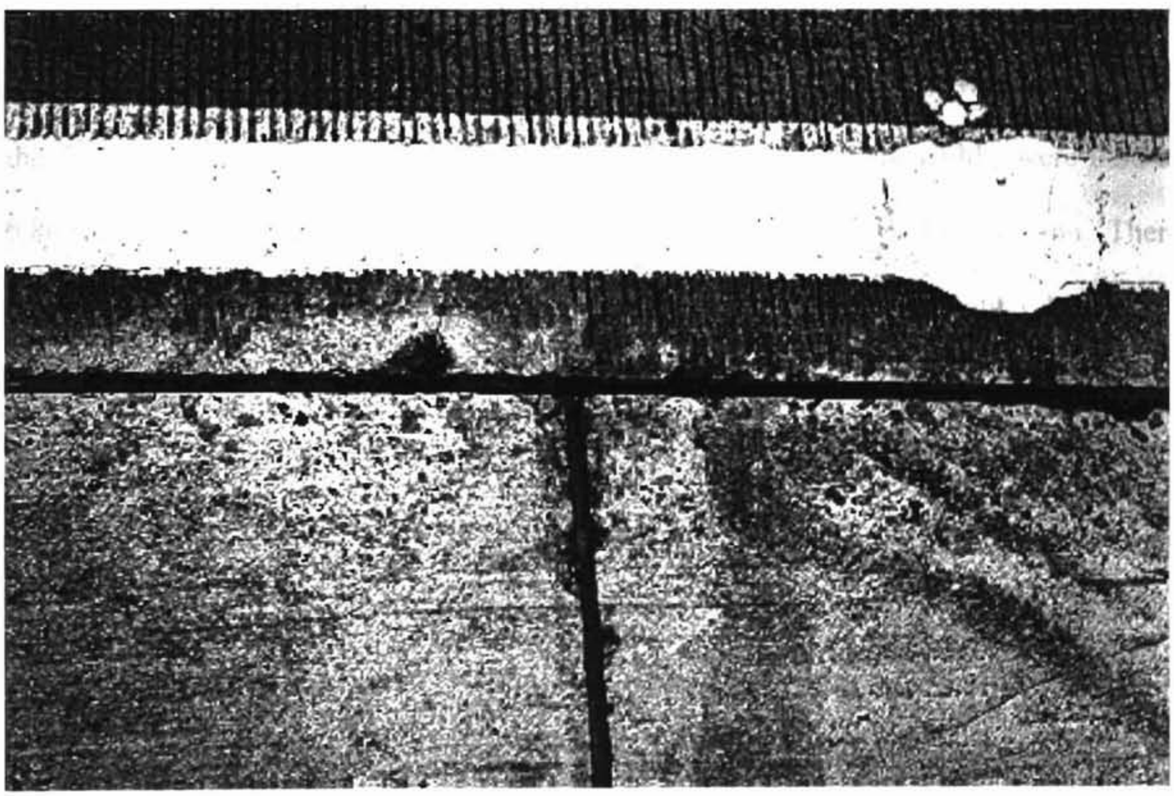


Figure A44. Relative movement between CRC slab and shoulders near terminal joint.

CRCP.16
Division: 2
Project #: F-299(45)
Survey date: July 24, 1998
County: Atoka
Location: US-69 north of Chockie

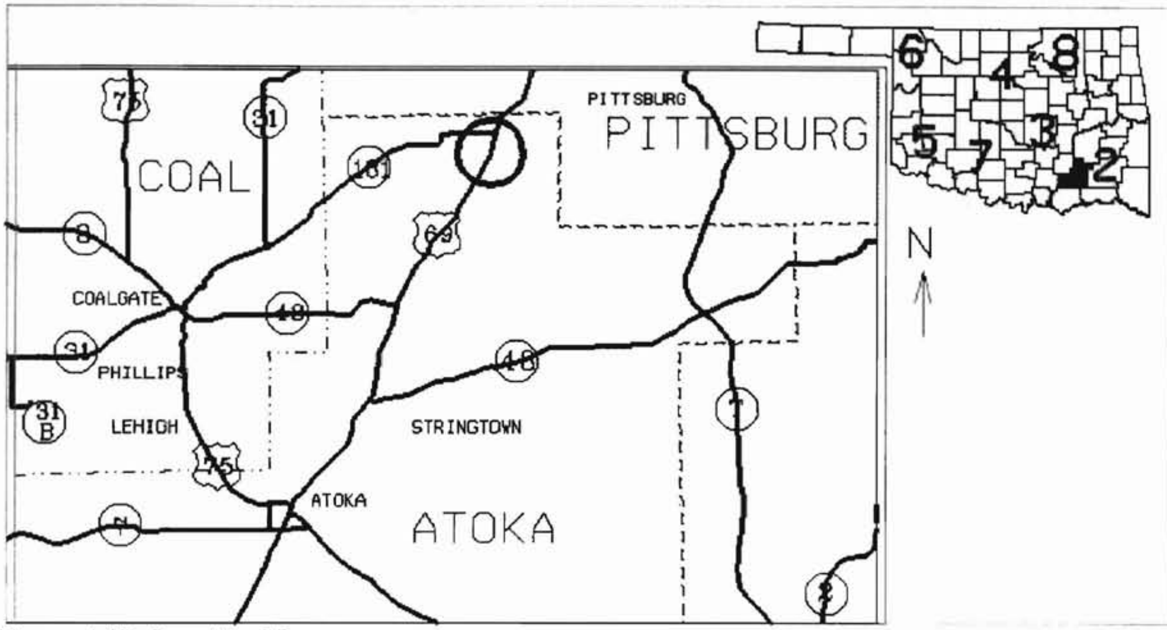


Figure A45. Location Map

Direction of travel of Survey Team: Northbound

This section was 2.253 km long with transverse cracks at 2.0 to 4.5 m spacings in the first third, and 1.0 to 2.0 m in the rest of the pavement. Crack widths were 0.30 to 0.80 mm in the first third of the way and 0.20 to 0.60 mm in the rest of the section. There were no Y-cracking, no clustering, no spalling, but one punchout of about 1.1 m^2. See Figure A46.

Direction of travel of Survey Team: Southbound

Transverse crack spacings were 1.8 to 4.5 m for this direction. Crack widths were 0.50 to 0.80 mm for the first third along the length, and 0.70 to 1.20 mm for the rest of the pavement. There was spalling along the cracks. Punchouts and repairs were over fifty in the 11.88-km stretch. See Figure A47.

Figure A46. Typical pavement condition of F-299(45) northbound.

Figure A47. Typical shoulder and pavement condition of F-299(45) southbound.

CRCP.17		**Survey date:**	**July 24, 1998**
Division:	**2**	**County:**	**Atoka**
Project #:	**F-299(35)**	**Location:**	**US-69 Springtown to Chockie**

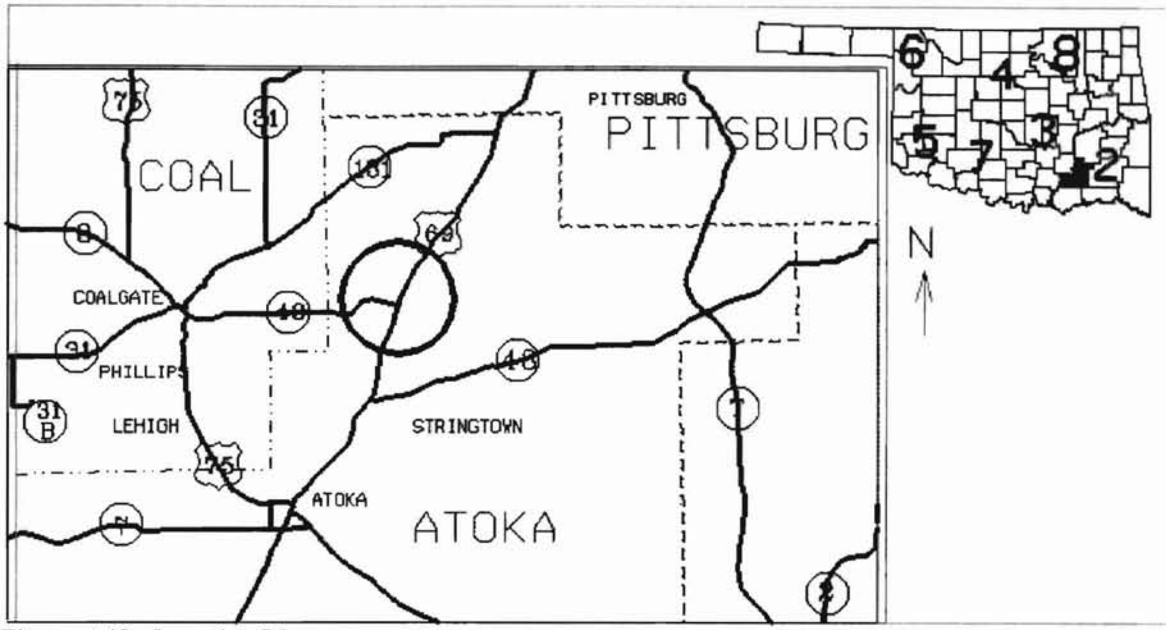


Figure A48. Location Map

Direction of travel of Survey Team: Northbound

Transverse cracks spacings range from 1.2 to2.0 m. Crack widths were 0.40 to 0.90 mm at the beginning of the project and wider northwards. There was spalling at the cracks. In general, the northbound lanes has fewer punchouts and repairs per kilometer than the southbound lanes. The length of CRCP in this direction is only 1.77 km. See Figure A49.

Direction of travel of Survey Team: Southbound

Transverse crack spacings were 1.8 to 4.5 m in the first third and 1.2 to 2.0 m in the rest of the pavement in this direction. Crack widths were about 0.60 mm. The length of CRCP is about 12 km. More than ninety punchouts and repairs of various sizes counted in this stretch. See Figure A50.

Figure A49. Typical pavement condition on F-299(35) northbound.

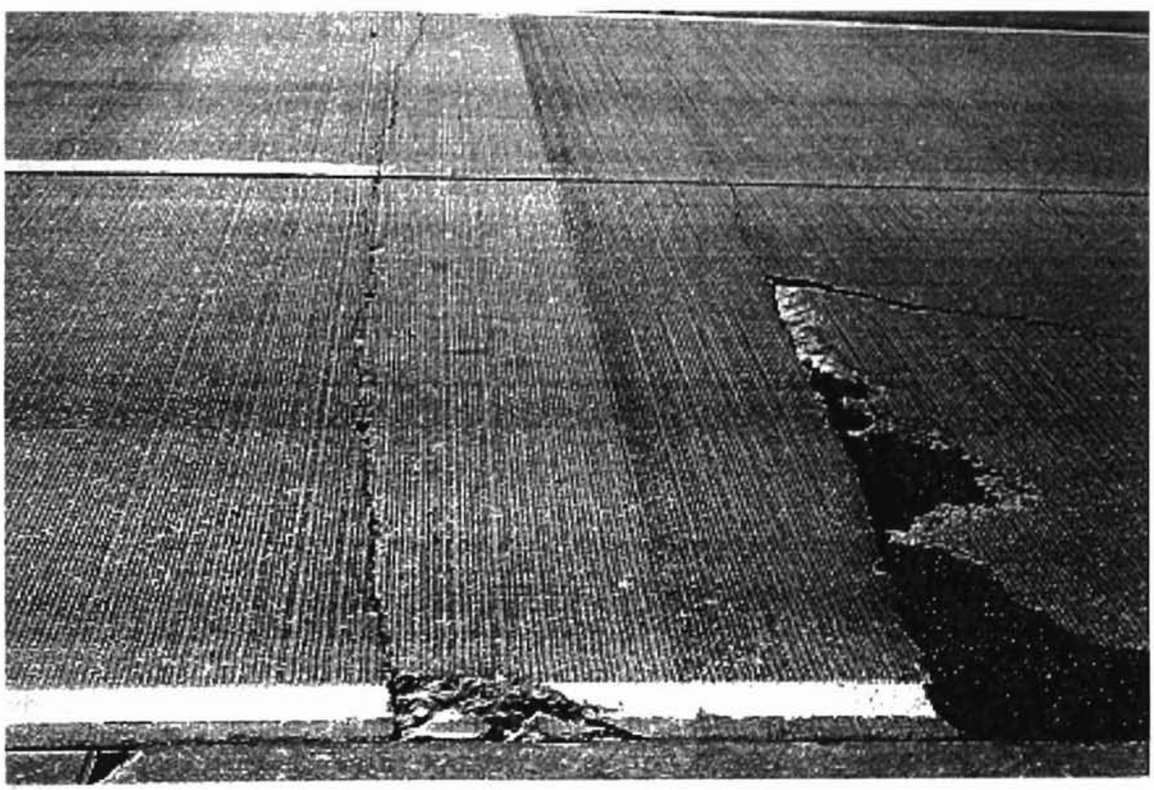


Figure A50. Punchout and deteriorated patch on F-299(35) southbound.

CRCP.18 | **Survey date: July 24, 1998**
Division: 2 | **County: Atoka**
Project #: F-299(99) | **Location: US69/US75**

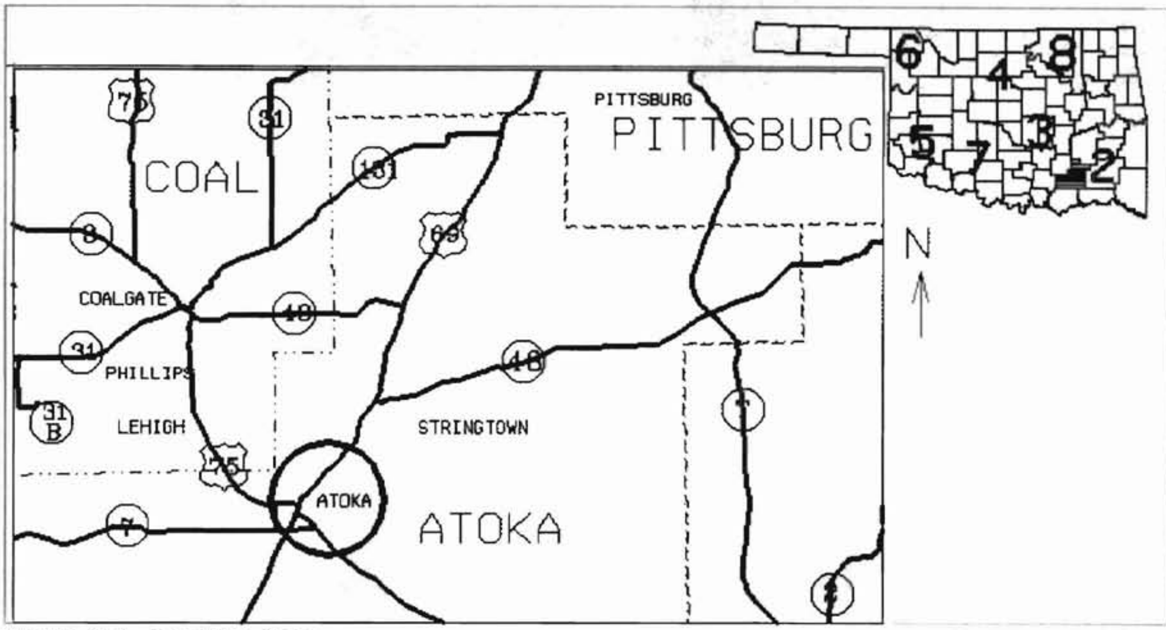


Figure A51. Location Map

Direction of travel of Survey Team: North bound

Transverse crack spacings range from 0.6 to1.5 m. Crack widths were 0.20 to 0.60 mm. There were some Y-cracks and clustering of cracks, but no spalling, no punchouts and no repairs. There were no longitudinal cracks, no scaling, no blowups and no popouts. See Figure A52.

Direction of travel of Survey Team: Southbound

The spacing of transverse cracks was generally between 0.6 and 1.5 m. Crack widths were about 0.20 to 0.60 mm for the whole length. There were no longitudinal cracks, no spalling, no popouts and no blowups. However, there was one punchout of about 0.1 m^2 in size. The joint sealer in the shoulder has come out of the joint at one location. See Figure A53. The ride on the CRCP was excellent.

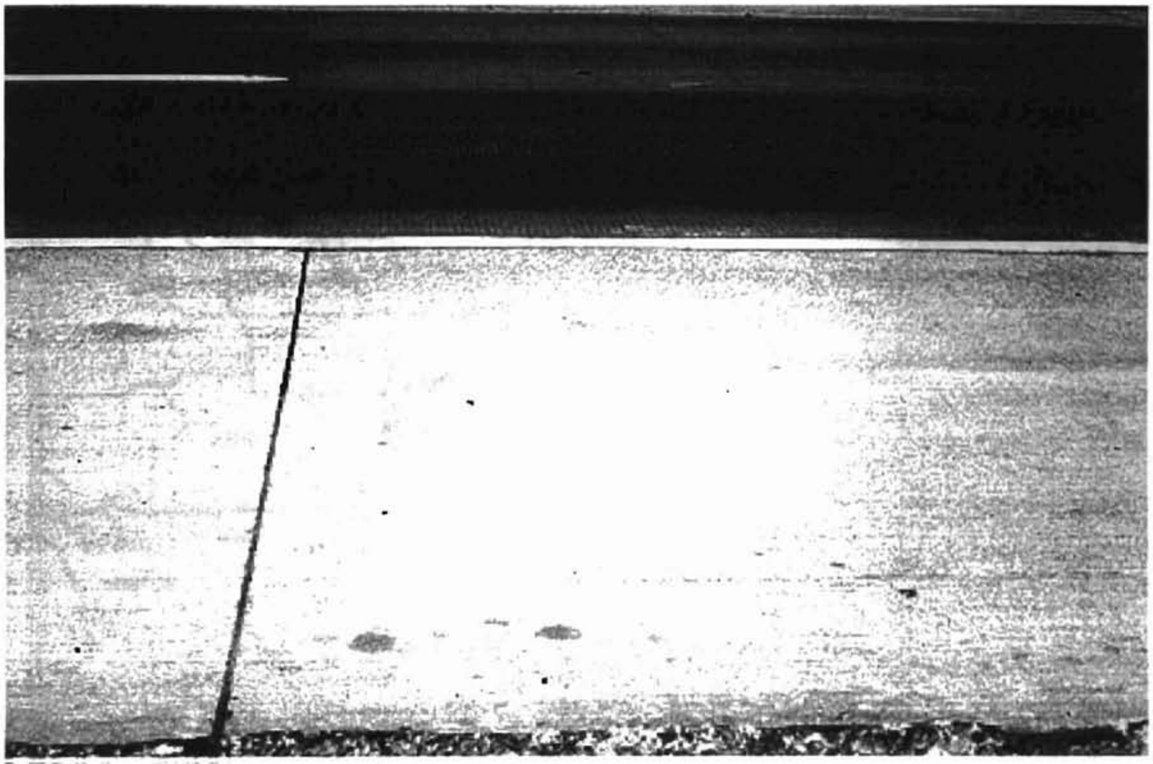


Figure A52. Typical condition of shoulder and pavement of F-299(99) northbound.

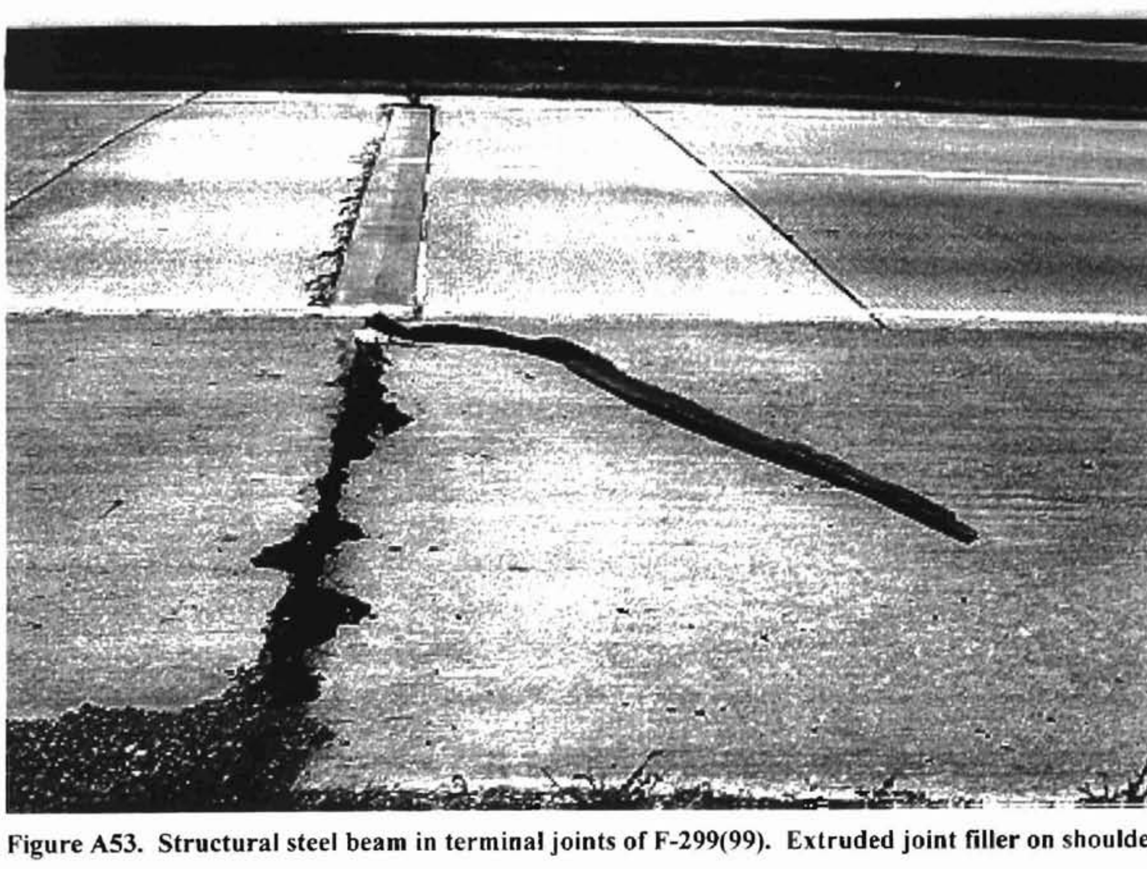


Figure A53. Structural steel beam in terminal joints of F-299(99). Extruded joint filler on shoulder

CRCP.19 **Survey date:** **July 23, 1998**

Division: **2** **County:** **Bryan**

Project #: **F-219(35)** **Location:** **US 69 Caddo to Armstrong**

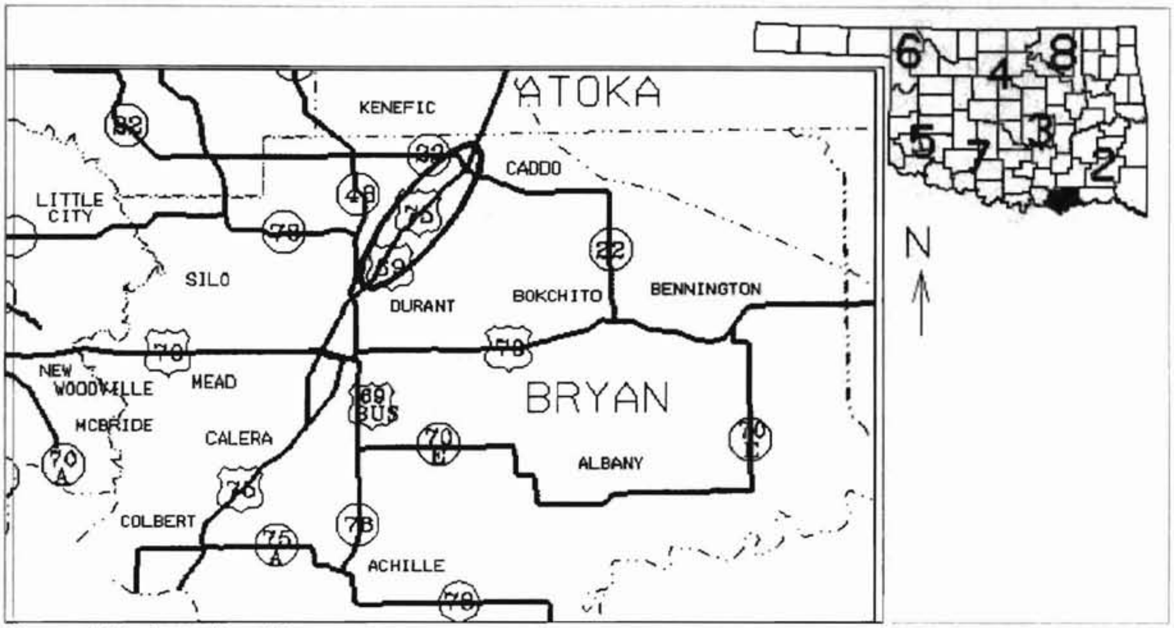


Figure A54. Location Map

Direction of travel of Survey Team: Northbound

The project has more than 30 m length of asphalt overlay at the beginning. Transverse cracks had severe spalling. Punchouts and repairs were numerous, following each other at short intervals. See Figure A55.

Direction of travel of Survey Team: Southbound

This project has clustered cracks, Y-cracking, longitudinal cracks, spalling, and punchouts and repairs at a staggering one hundred and fifty locations in the 12.7 km section. The number of failures makes this an unusual project. See Figure A56.

Figure A55. Patch on F-219(35) northbound.

Figure A56. Patches on F-219(35) southbound.

CRCP.20		**Survey date:**	**July 1, 1998**
Division:	**3**	**County:**	**Pontotoc**
Project #:	**MAF-235(009)**	**Location:**	**SH 3W Ada**

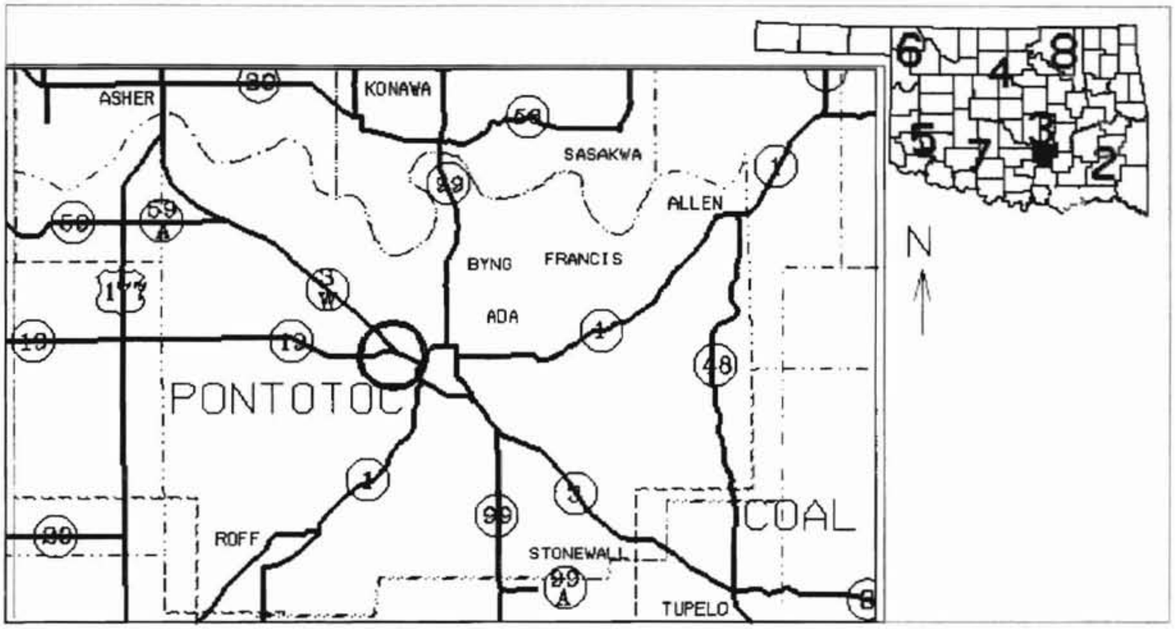


Figure A57. Location Map

Direction of travel of Survey Team: Eastbound

Transverse Cracks were generally straight across the pavement. Crack spacings were around 1.5 m. Crack widths were in the region of 0.40 mm at most locations. There were no spalling along the cracks, no longitudinal cracking, no punchouts, and no repairs on the project. The CRCP provided an excellent riding surface and driver comfort. See Figure A58.

Direction of travel of Survey Team: Westbound

Similar to eastbound lanes. Transverse crack spacings were 0.9 to 1.5 m. The crack widths were 0.40 to 0.80 mm. There were a few Y-cracks. The cracks position did not seem to be influenced by the 15mm wide lines cut in the shoulders. There were no longitudinal cracks. See Figure A59.

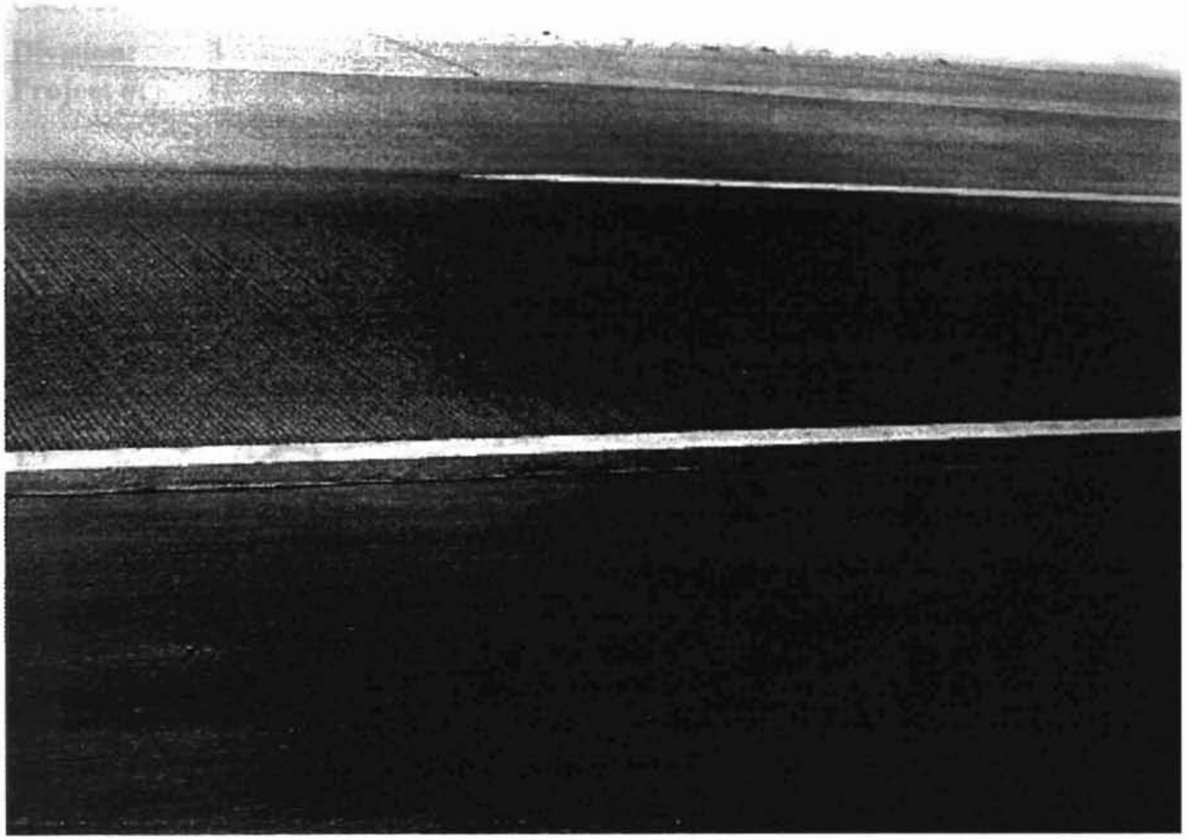


Figure A58. Typical condition of MAF-235 eastbound.

Figure A59. Typical condition of MAF-235(009) westbound.

CRCP.21		**Survey date:**	**July 23, 1998**
Division:	**3**	**County:**	**Okfuskee**
Project #:	**IR-40-5(169)**	**Location:**	**I-40 east of Okemah**

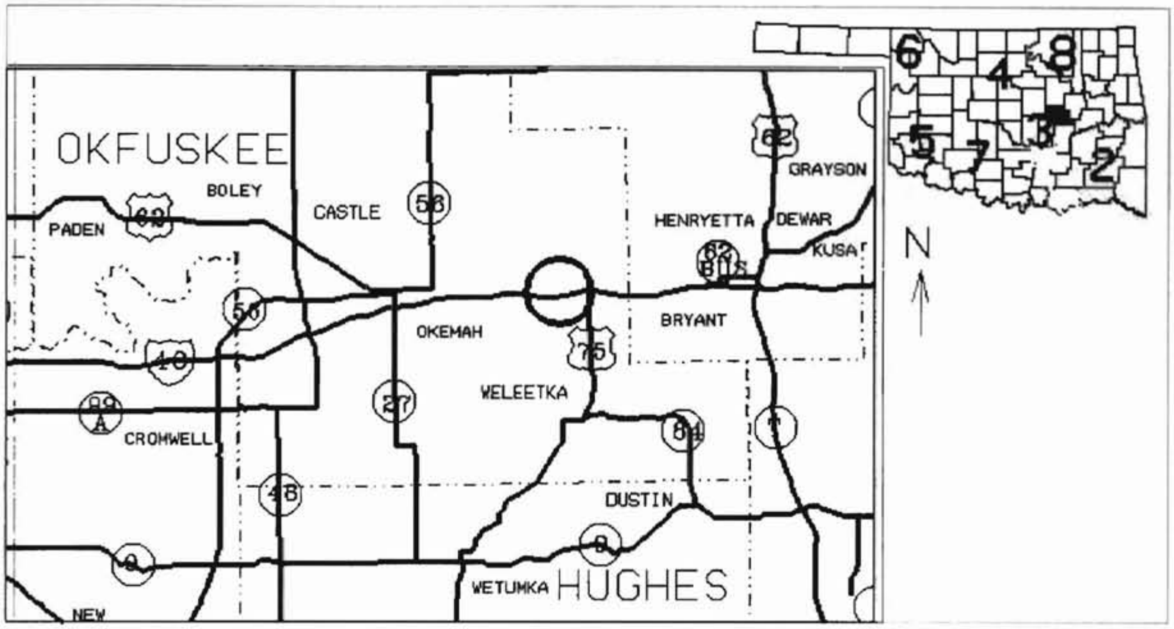


Figure A60. Location Map

Direction of travel of Survey Team: Eastbound

Transverse crack spacings were 0.9 to 1.5 m. The crack widths were 0.25 to 0.55 mm. There were no longitudinal cracks. There was a 0.2 m^2 punchout and about five repairs of a total of about 3 m^2. There were defective construction joints with a total repaired area of about 4.5 m^2. See Figure A61.

Direction of travel of Survey Team: Westbound

The transverse crack spacing were 0.9 to 2.0 m centers. There is a lot of spalling at the cracks. Punchouts and repairs counted were more than seventy for this direction alone. See Figure A62. About half of the defect counted was in the first one-third of the length. In general, the punchouts were at the location of the shoulder cuts. There was also a large patch on an on-ramp. Despite the above, the ride on the CRC was good.

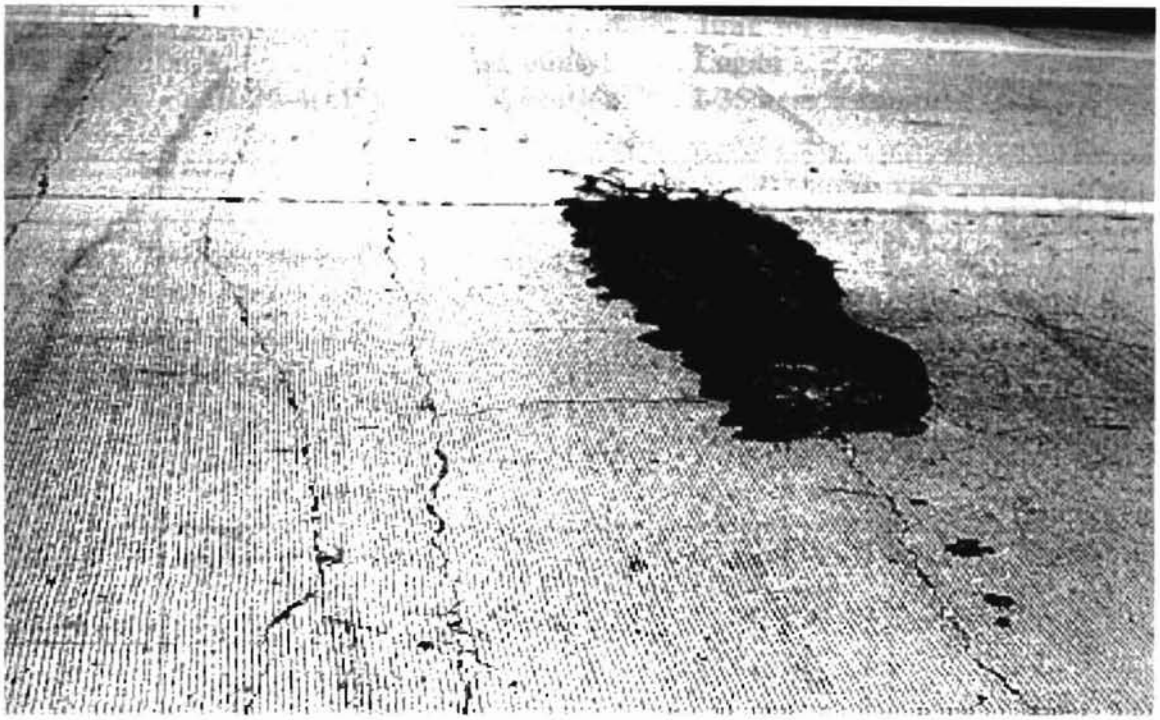


Figure A61. Repair of punchout on I-40 using asphalt concrete patching.

Figure A62. Patch on IR-40-5(169) westbound.

CRCP.22		**Survey date:**	**June 30, 1998**
Division:	**4**	**County:**	**Logan**
Project #:	**IR-35-4(115)**	**Location:**	**I-35 near Edmond**

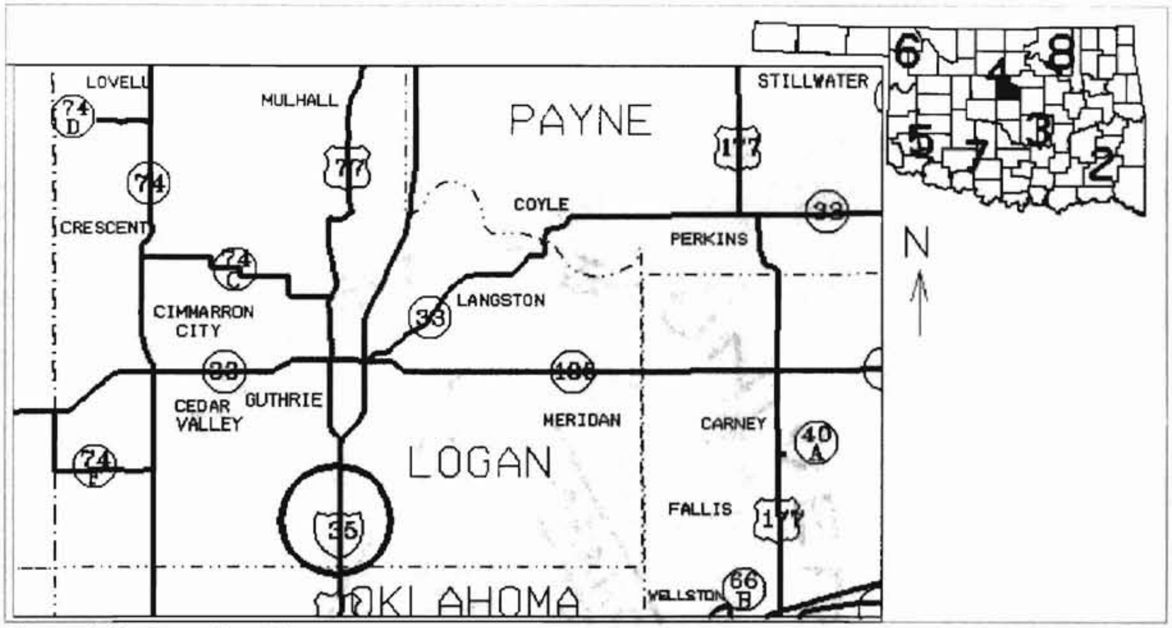


Figure A63. Location Map

Direction of travel of Survey Team: Northbound

The sawed-joints in the shoulders were at 4.5 m intervals and lined up on the two sides of the travel pavement. Crack widths were generally in the region of 0.33 mm. Sympathetic transverse cracks occur across the pavement, originating from the cut on one shoulder to the cut on the other side. This regularity of the sympathetic cracks persisted for about half the length of the pavement. Some sections have one or two extra cracks in between the regular 4.5 m intervals. There were a few locations of clusters of transverse crack patterns; about one every three hundred meters. One notable observation about this project was the consistently defective construction joints. This does not have any effect on the smoothness and excellent driver comfort that this CRCP offered. See Figure A64.

Direction of travel of Survey Team: Southbound

The pavement condition was similar to northbound lanes.

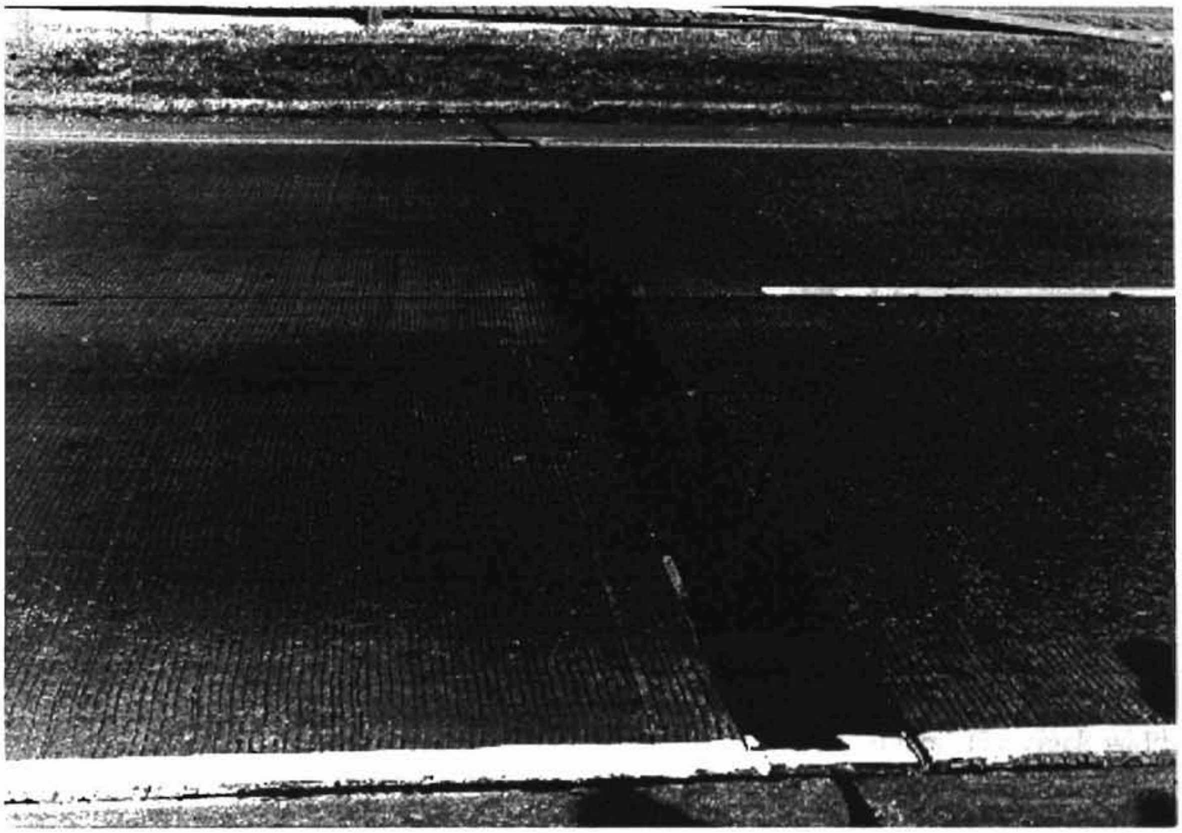


Figure A64. Structural steel beam at terminal joint

CRCP.23		**Survey date:**	**June 30, 1998**
Division:	**4**	**County:**	**Noble**
Project #:	**MAIR-35-4(111)**	**Location:**	**I-35 near Perry**

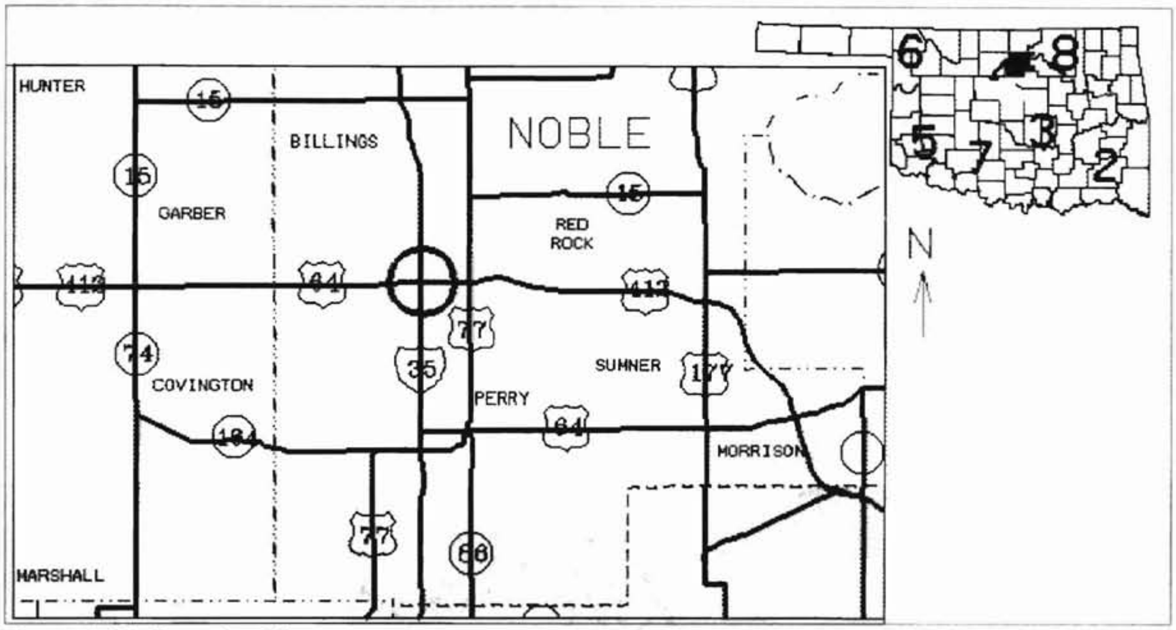


Figure A65. Location Map

Direction of travel of Survey Team: Northbound

Transverse Cracks varied in spacing from 2.0 to 4.5 m centers. The crack widths were generally in the region of .30 to 0.80 mm. There were a few cluster crack patterns. It was quite noticeable that the crack patterns follow the cuts in the shoulders. When the cuts in the shoulders do not line up on either side of the pavement, the cracks do not generally go from cut right across to the other side, but follow an irregular pattern. See Figure A66. It was also noticed that the cracks are not affected by the difference in depth of the skid resistance groves. There were spalling at some cracks. There were also punchouts at a few spots. These have been repaired with asphaltic concrete cover-up.

There seems to be a problem with the method of building construction joints. This is evident from the repairs to the concrete done during the construction and before opening to traffic, and the present spalling and patching at the joints. The on/off ramps also seem to be areas susceptible to damage or faulty construction. Despite the problems noted, the CRCP provided an excellent ride.

Direction of travel of Survey Team: Southbound

The pavement in this direction did not differ much from that in the northbound direction.

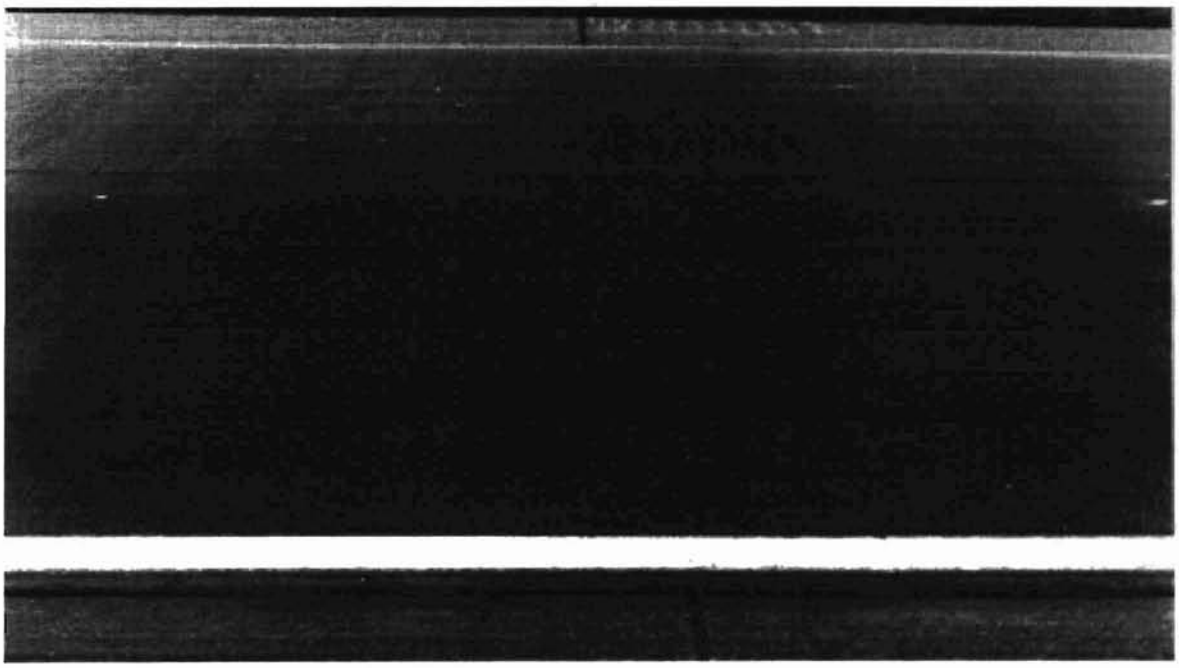


Figure A66. Typical pavement condition on MAIR-35-4(111).

CRCP.24		**Survey date:**	**June 30, 1998**
Division:	**4**	**County:**	**Oklahoma**
Project #:	**F-385(043)**	**Location:**	**SH 74 Lake Hefner Parkway**

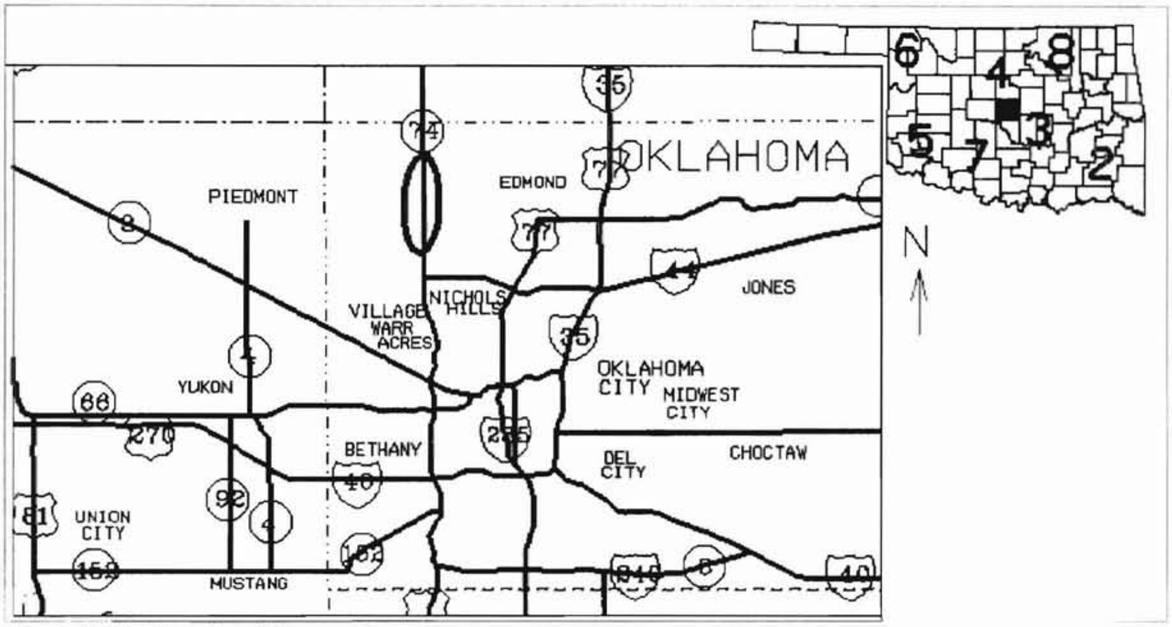


Figure A67. Location Map

Direction of travel of Survey Team: Northbound

Transverse Cracks were generally straight across the pavement. Crack spacings were 0.3 to 2.0 m centers. Some sections of the pavement have wider transverse crack spacing. Crack widths were in the region of 0.45 to 0.90 mm at most locations. There was some spalling along the cracks. Although there were some Y-cracks, there was no longitudinal cracking, punchouts, and no repairs on the CRCP. The CRCP provided a most excellent riding surface and driver comfort.

Direction of travel of Survey Team: Southbound

A similar pattern of pavement behavior and response to traffic and environment is seen here as it was for the northbound lanes. See Figure 68

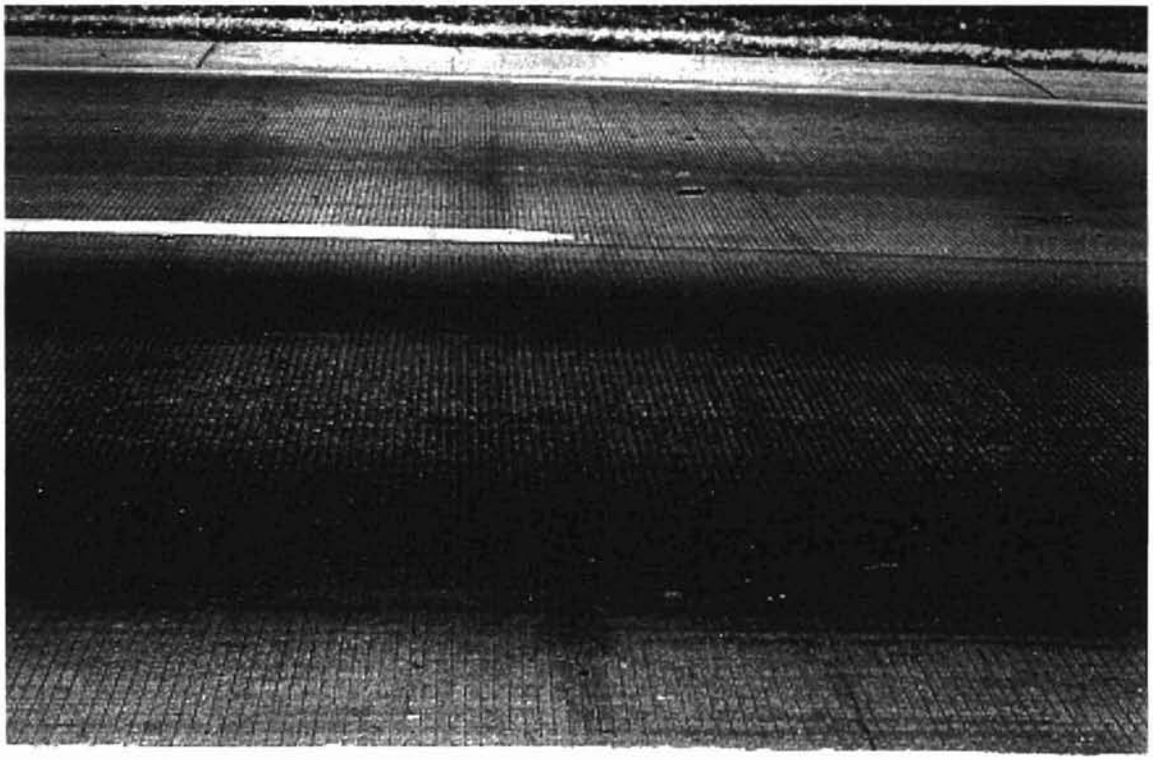


Figure A68. Typical pavement condition on F-385(043).

CRCP.25		**Survey date:**	**June 30, 1998**
Division:	**4**	**County:**	**Oklahoma**
Project #:	**F-385(055)**	**Location:**	**SH 74 Lake Hefner Parkway**

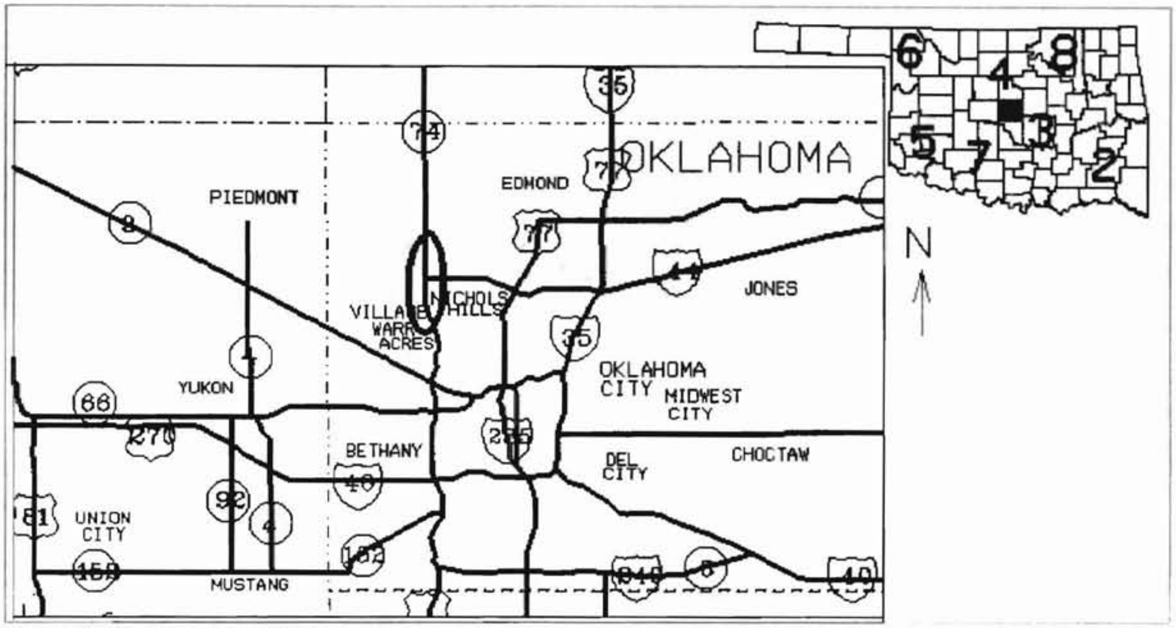


Figure A69. Location Map

Direction of travel of Survey Team: Northbound

Transverse Crack spacings vary widely, but generally from 0.3 to 2.0 m centers. Some sections of the pavement have wider transverse crack spacing. Crack widths were in the region of 0.45 to 0.90 mm at most locations. There was a bit of spalling along the cracks. There were some Y-cracks at a number of areas, but no longitudinal cracking, no punchouts, and no repairs on the CRCP.

Direction of travel of Survey Team: Southbound

The condition indicators were similar to those on the northbound lanes. The use of a Crack Comparator to obtain crack width is shown in Figure 70. A typical outlet to CRCP underdrain is in Figure 71.

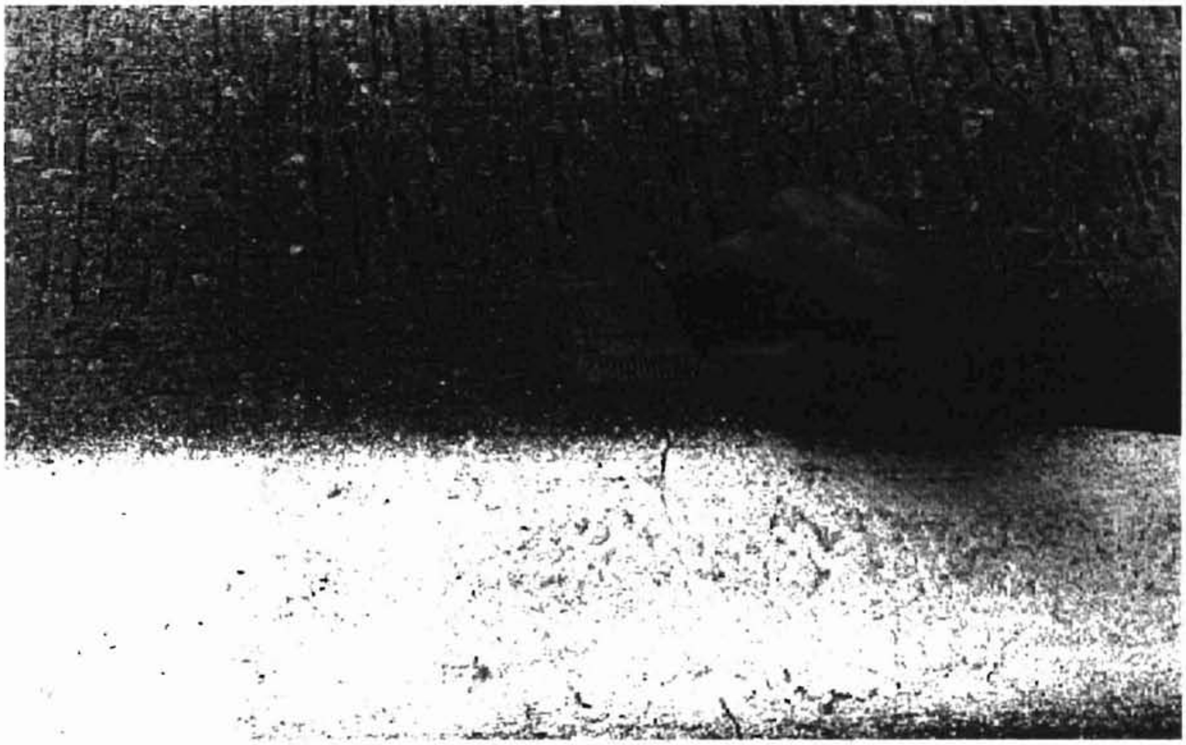


Figure A70. Using a Crack Comparator to estimate crack width.

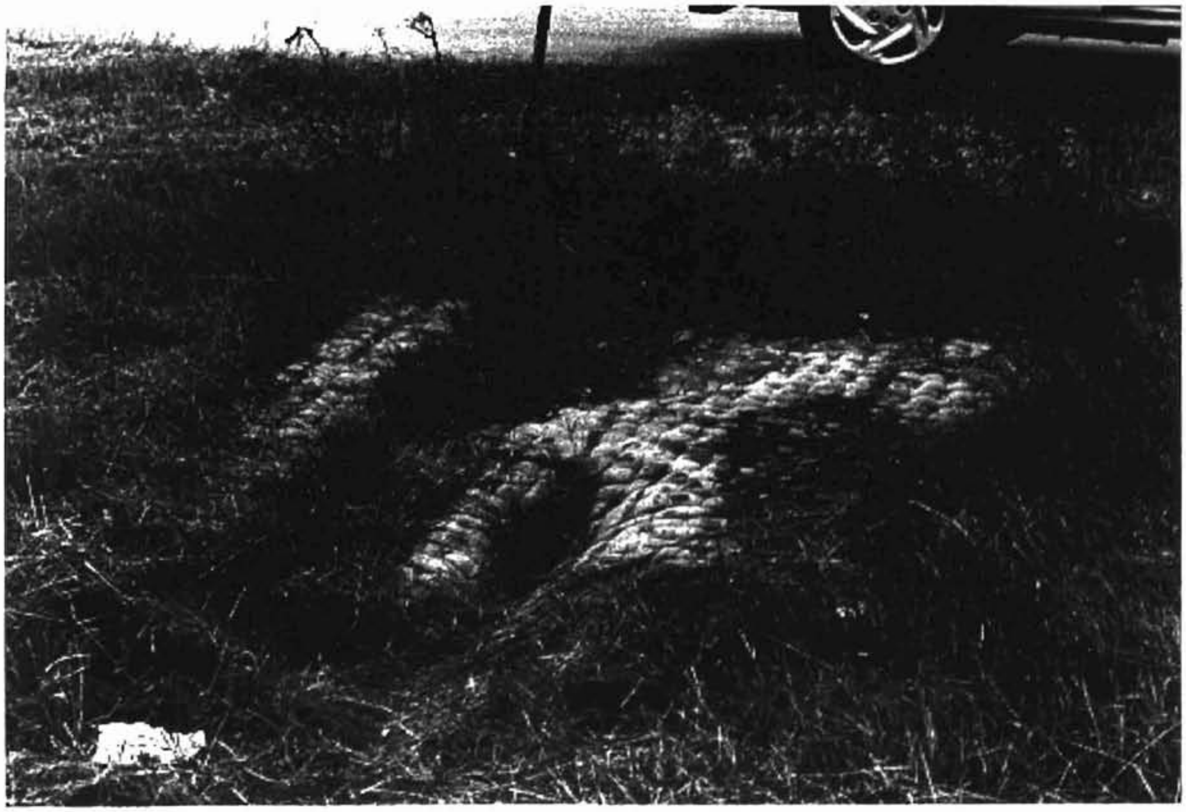


Figure A71. Outlet of drain under pavement.

CRCP.26 | **Survey date:** **June 30, 1998**
Division: **4** | **County:** **Oklahoma**
Project #: **MAF-385(054)** | **Location:** **SH 74 Lake Hefner Parkway**

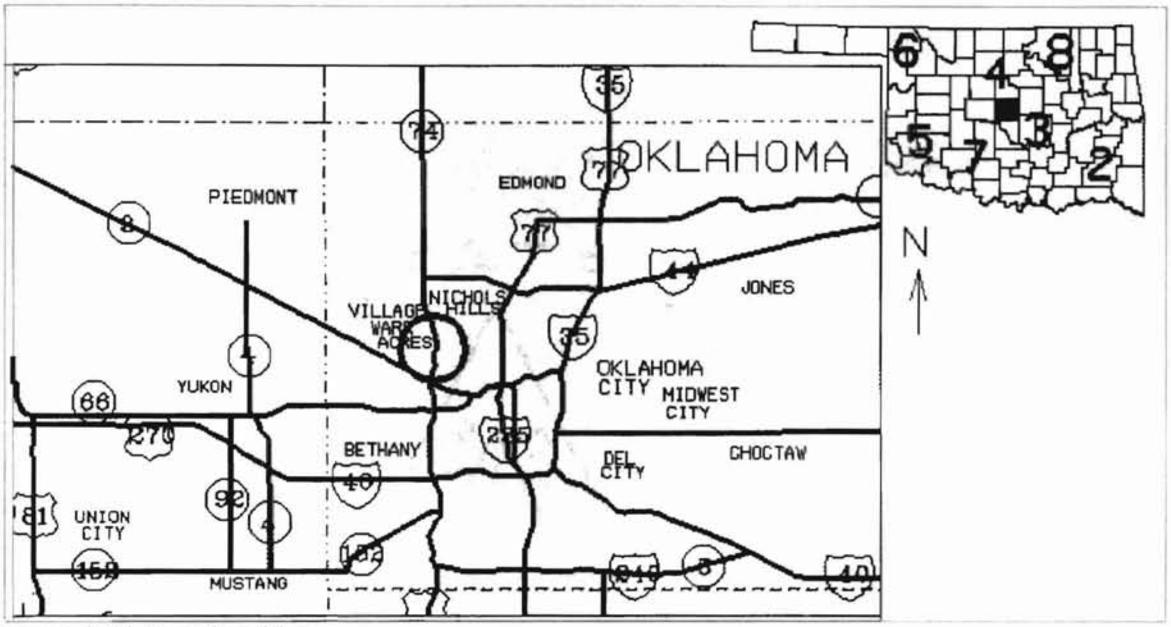


Figure A72. Location Map

Direction of travel of Survey Team: Northbound

Transverse Cracks were generally straight across the pavement. Crack spacings were 0.3 to 2.0 m centers. Some sections of the pavement have wider transverse crack spacings. Crack widths were in the region of 0.45 to 0.90 mm at most locations. There was a bit of spalling along the cracks. Although there were some Y-cracks, there was no longitudinal cracking, punchouts, and no repairs on the CRCP. The CRCP provided a most excellent riding surface and driver comfort.

Direction of travel of Survey Team: Southbound

Similar to north bound lanes. See Figure A73.

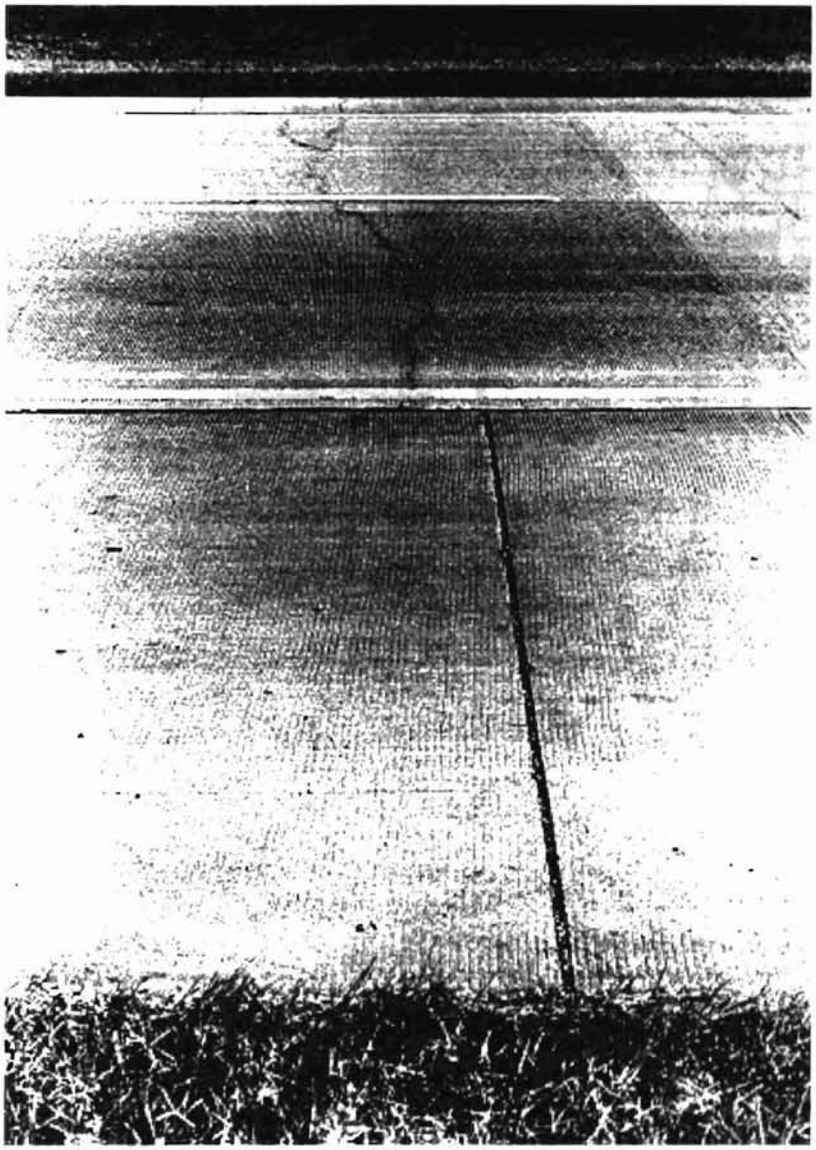


Figure A73. Typical pavement condition on MAF-385(054).

CRCP.27		**Survey date:**	**June 29, & July 27, 1998**
Division:	**5**	**County:**	**Beckam and Washita**
Project #:	**IM-40-(119)**	**Location:**	**Elk City**

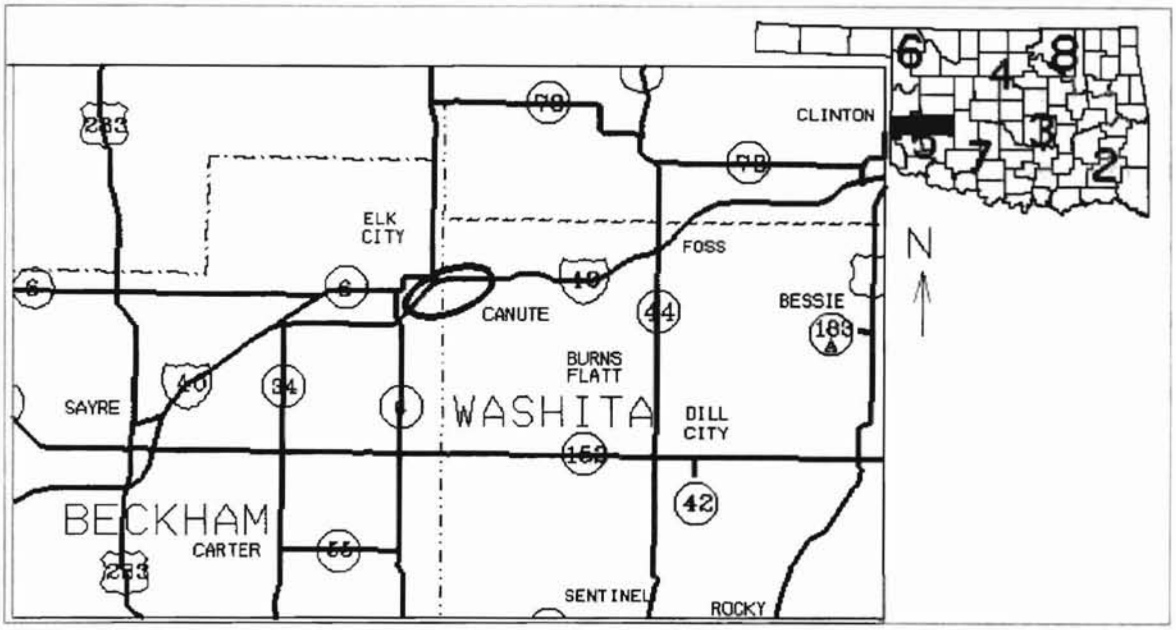


Figure A74. Location Map

Direction of travel of Survey Team: Eastbound

In the first two thirds of the length, the transverse crack spacings range from 0.3 m to 1.2 m, and in the last third, the spacings were 0.9 to 1.5 m. Crack widths were 0.50 mm to 1.20 mm in the first two thirds, and of the order of 0.40 mm to 0.90 mm in the last one-third. There were many Y-cracks and curved cracks. See Figure A75. Spalling has occurred at a number of the cracks. Longitudinal cracks have developed at a few areas of the pavement. The longitudinal cracks in the last third were much less than in the previous section. There were punchouts, generally in the outside traffic lane. The size of a punchout filled with asphalt concrete was about 0.6 m by 3.6 m (lane width). The repairs with cement concrete range in size from 0.6 m to 4.5 m by 3.6 m lane width. The terminal joints were not damaged in any way. Construction joints were good. There were no signs of repairs due to construction defects. The ride was excellent.

Direction of travel of Survey Team: Westbound

The first two thirds of the pavement has transverse cracking at 0.5 m to 1.5 m apart. The last third had transverse cracking spaced wider than the initial sections and generally between 1.0 m and 2.0 m apart. The cracks were, for the most part, straight across the pavement, although there was a significant number of curved cracks. There was some Y-cracking. Spalling has occurred at a number of cracks. Crack widths were of the order of 0.40 mm to 0.90 mm. No longitudinal cracking was seen to have developed on this section of the pavement. There was one small punchout near the on/off ramp at the beginning of the westbound direction. There was a repair and drainage constructed to improve performance of the slow draining base/subbase. See Figure A76. The terminal joints were not damaged. Construction joints were all good. The ride was smooth.

Figure A75. Curved cracks typical on IM-40-2(119) eastbound.

Fig. A76. Repair of punchout. Drain constructed to increase drainage under pavement.

CRCP.28 | **Survey date: July 27, 1998**
Division: 6 | **County: Cimarron**
Project #: MAF-350(11) | **Location: SH-3 near Boise City**

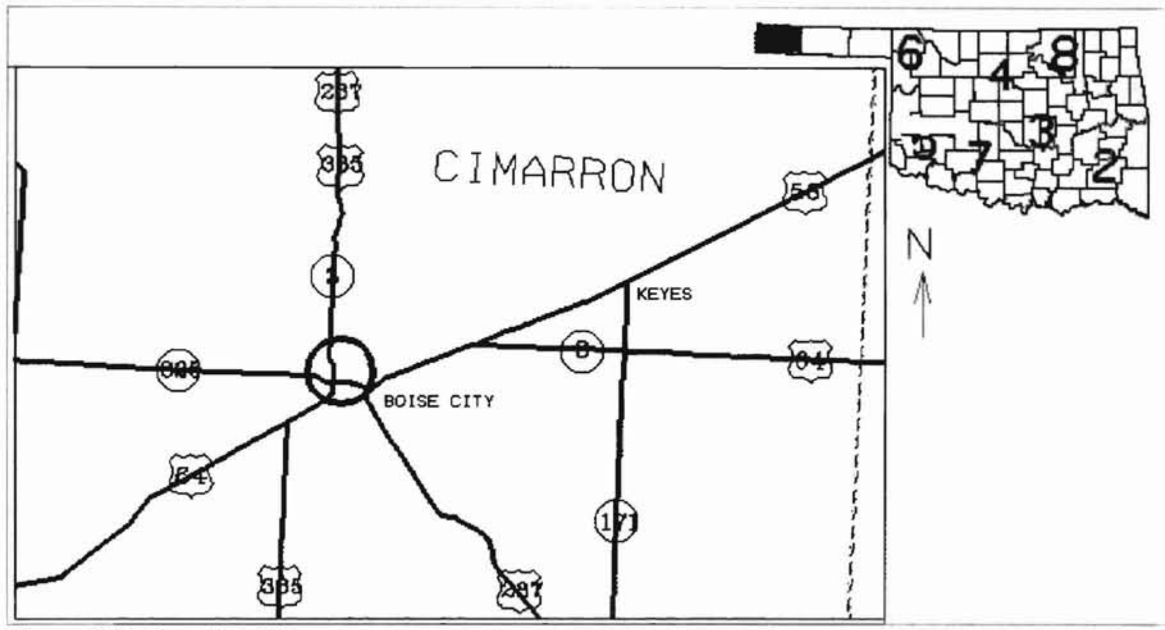


Figure A77. Location Map

Direction of travel of Survey Team: Eastbound

Transverse Cracking has developed at 1.5 m to 2.0 m apart. Crack widths were of the order of 0.20 mm to 0.50 mm. The cracks were generally straight across the pavement. There were some longitudinal cracks in the pavement, but no Y-cracking and no curved cracks, no spalling, no punchouts, and no repairs. The terminal joints were not damaged in any way. Construction joints were all good. The ride was excellent. See Figure A78.

Direction of travel of Survey Team: Westbound

The pavement condition was the same as the eastbound lanes. See Figure A79.

Figure A78. Typical traffic type in background of MAF-350(11).

Figure A79. Typical pavement condition of MAF-350(11).

CRCP.29
Division: **6**
Project No.: **NH-8N(001)**

Survey date: **July 27, 1998**
County: **Texas**
Location: **US 54 near Guymon**

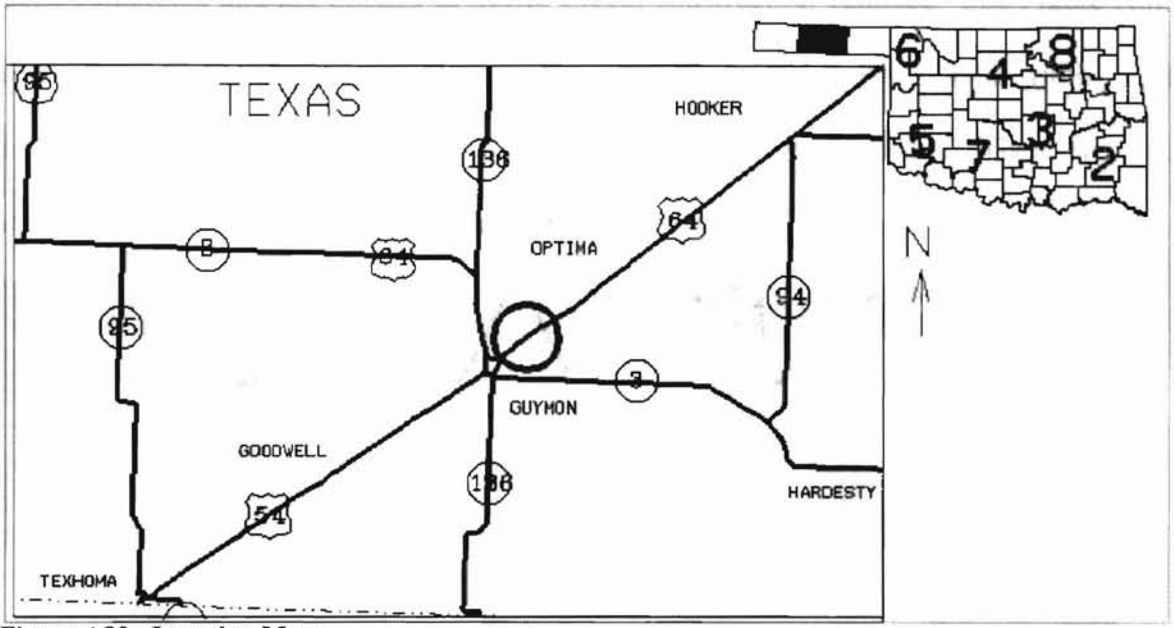


Figure A80. Location Map

Direction of travel of survey team: Eastbound

Transverse cracks were at 2.0 m to 4.5 m apart for the whole length. Crack widths were of the order of 0.10 mm to 0.20 mm. The cracks were generally straight across the pavement. There were no clustered cracks, no Y-cracking and no spalling at the cracks.

There were no longitudinal cracks anywhere and no punchouts for the whole length. The terminal joints were not damaged in any way and all construction joints looked good. There were no signs of construction defects. See Figure A81. The ride was excellent.

Direction of travel of survey team: Westbound

This section is under construction at the time of survey. This pavement has just been completed and not opened to traffic except construction vehicles. See Figure A82. For the length completed, transverse cracks were about 4.5 m apart. Crack widths were about 0.10 mm. Cracks were generally straight across the pavement. There were no clustered cracks, no Y-cracking and no longitudinal cracking.

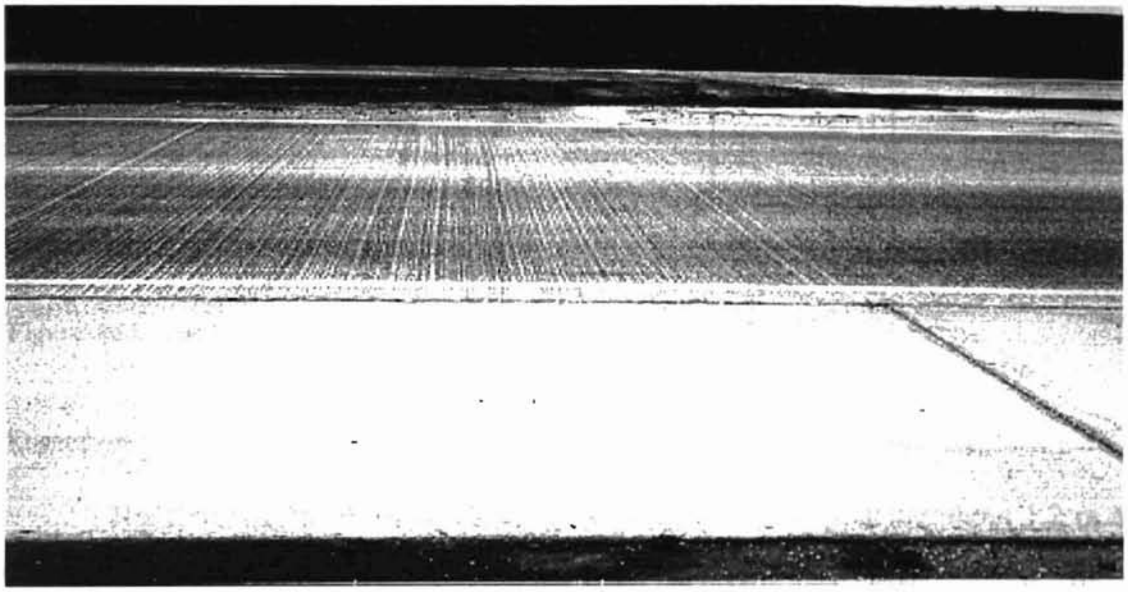


Figure A81. Typical pavement condition on NH-8N(001) eastbound.

Figure A82 Westbound NH-8N(001) under construction. Traffic moving in both directions in eastbound lanes.

CRCP.30 **Survey date:** **June 29, 1998**

Division: **7** **County:** **Comanche**

Project #: **MAM 7780(002)** **Location:** **Rogers Lane in Lawton**

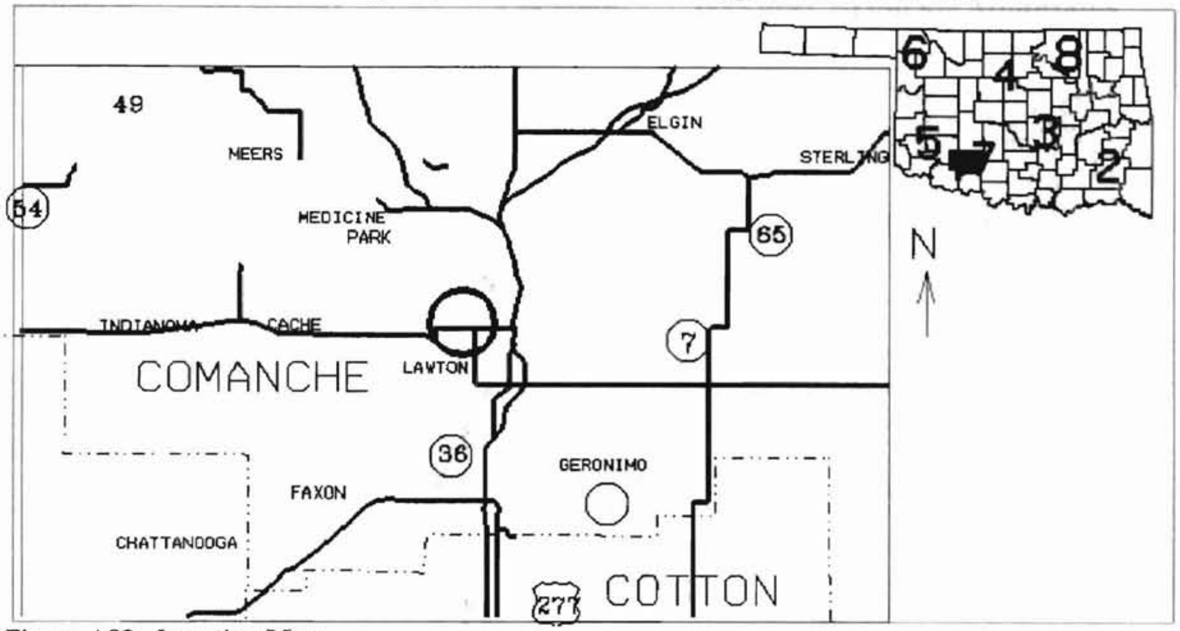


Figure A83. Location Map

Direction of travel of Survey Team: Eastbound

The first two thirds of this side had transverse cracks spacing about 1.2 m apart. Cracks were wider westbound, and of the order of 0.50 mm to 1.20 mm. Spalling has occurred at a number of cracks. The ride was good.

Direction of travel of survey team: Westbound

For the first two thirds of the length the transverse cracks were at 0.5 m to 1.5 m apart and for the last third the spacings were about 1.0 m to 2.0 m apart. Crack widths were about 0.40 mm. The cracks were straight across the pavement. There was little Y-cracking and no curved cracks. Light spalling has occurred at some cracks. There were no longitudinal cracks in the pavement and no punchouts. Terminal joints were not damaged. Construction joints were good. There were no signs of construction defects.

CRCP.31 **Survey date: July 1, 1998**

Division:	**7**	**County:**	**Murray**
Project #:	**I-35-2(64)**	**Location:**	**I-35 near Arbuckle Mountains**

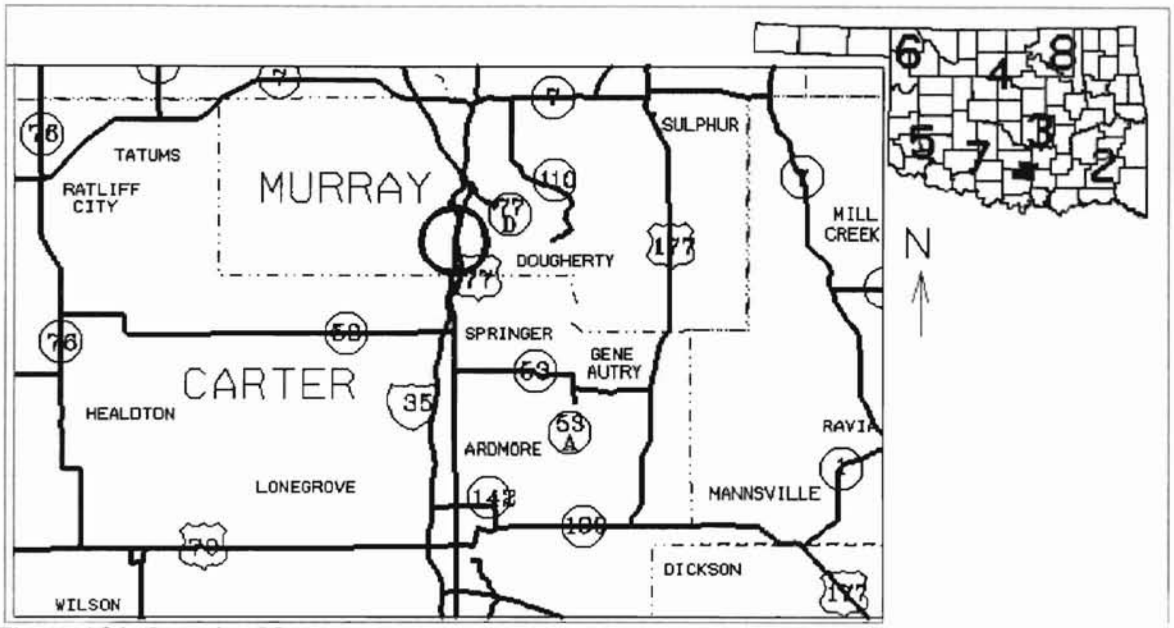


Figure A84. Location Map

Direction of travel of Survey Team: Northbound

Condition indicator parameters in this direction were similar to those of the southbound traffic lanes.

Direction of travel of Survey Team: Southbound

Transverse Crack spacings were 2.0 to 3.0 m centers. Crack widths were 1.0 to 2.00 mm. There is spalling at the cracks. Longitudinal cracks exist at a few sections. Punchouts are not that many, but there were locations with whole lane concrete patches and others with asphalt concrete overlay. It is noteworthy that, despite the numerous defects and repairs on the CRCP, the ride was good and comparable to a very good asphalt concrete pavement. See Figures 85, 86, 87, 88, 90, 92 and 93 for the general condition of CRCP on I-35 in the area.

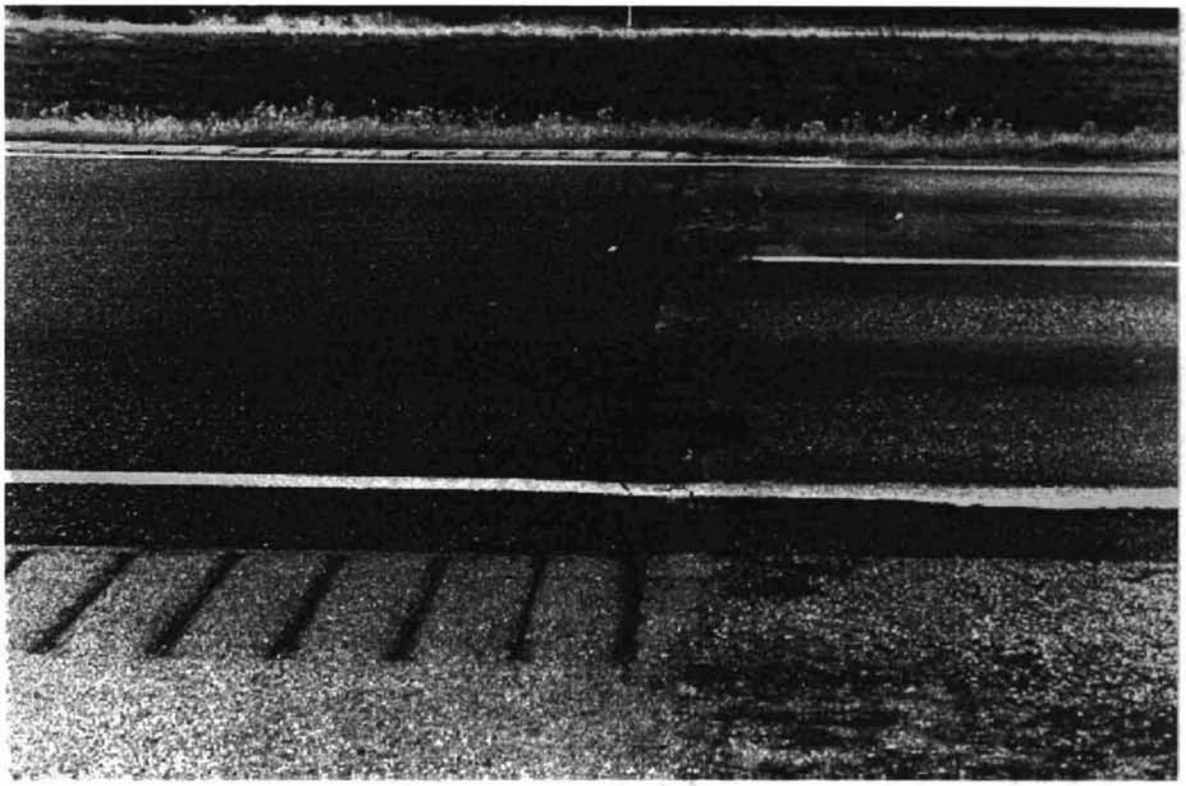


Figure A85. Asphalt overlay on CRCP.

Figure A86. Joint deterioration and patching.

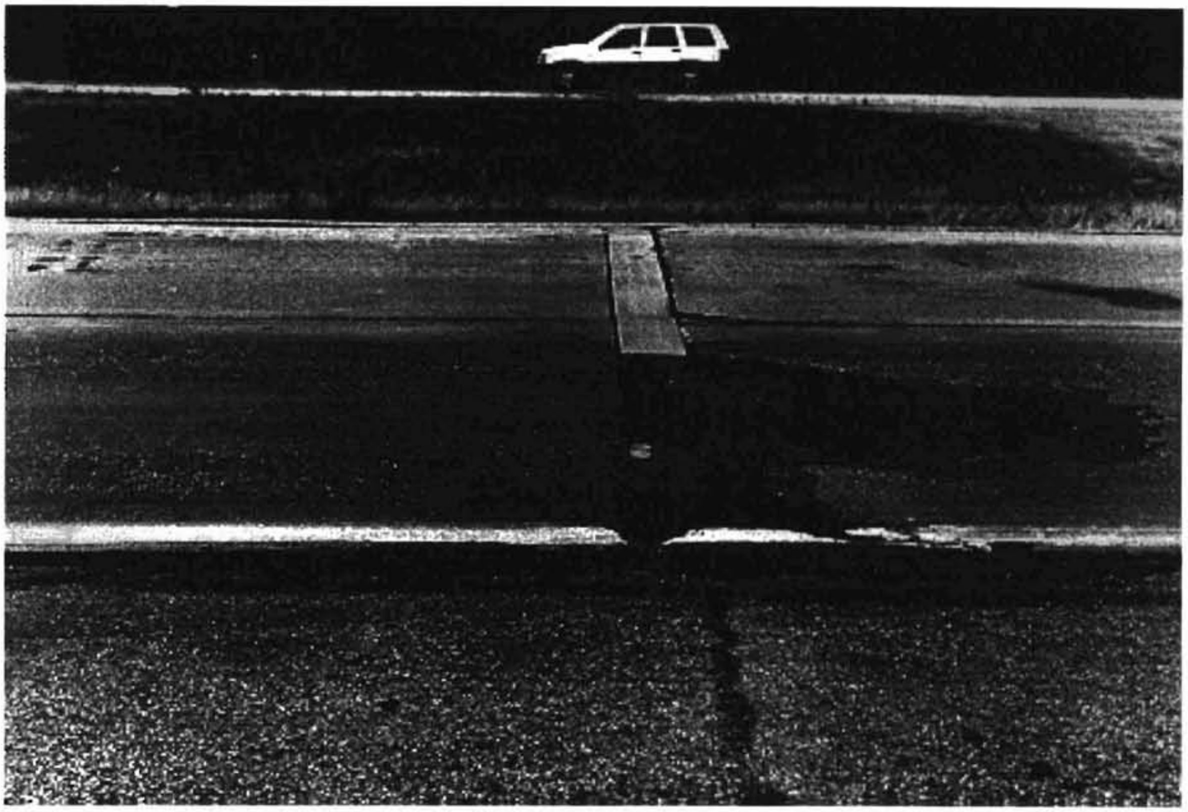


Figure A87. Terminal joint deterioration.

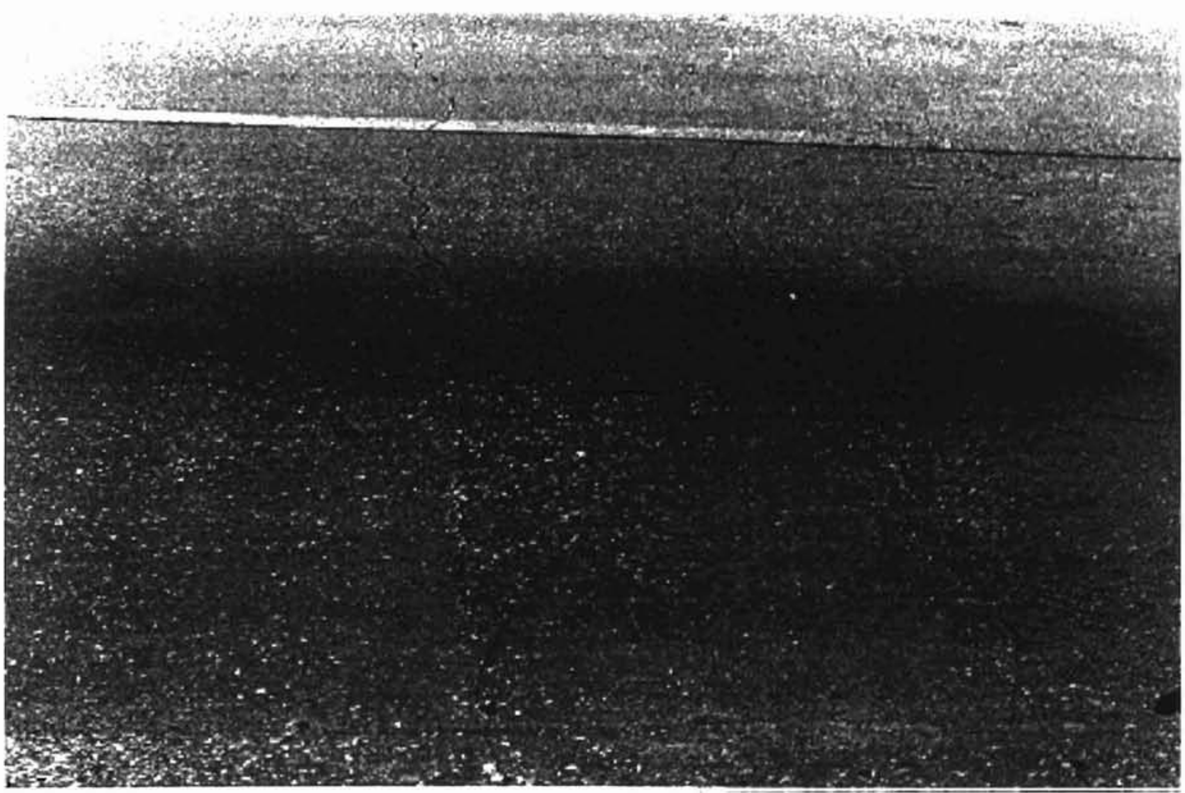


Figure A88. Wide transverse crack widths and a longitudinal crack on I-35

CRCP.32 | **Survey date: July 1, 1998**

Division:	**7**	**County:**	**Carter**
Project #:	**I-35-1(53)**	**Location:**	**I-35 south of Murray County**

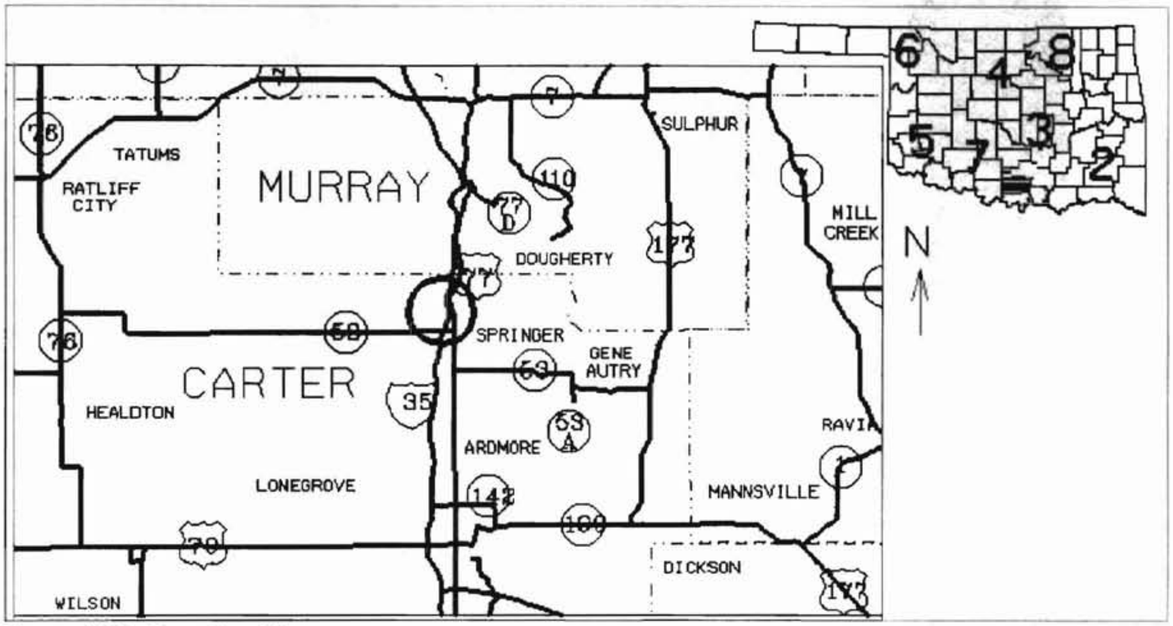


Figure A89. Location Map

Direction of travel of Survey Team: Northbound

The conditions here are very similar to the southbound traffic lanes. See Figures 85, 86, 87, 88, 90, 92 and 93 for the general condition of CRCP on I-35 in the area.

Direction of travel of Survey Team: Southbound

Transverse crack spacings were very regular in this section; at 1.2 to 1.8 m centers. Crack widths were 0.90 to 3.00 mm. There was some longitudinal cracking punchouts and patches at a number of places. This is one of the first CRCPs in the state and, though past its design life, could still provide some useful service.

Figure A90. Asphalt overlay typical on I-35 CRCPs in Murray and Carter counties.

CRCP.33 | **Survey date: July 1, 1998**
Division: 7 | **County: Carter**
Project #: I-35-1(48) | **Location: I-35 near Ardmore**

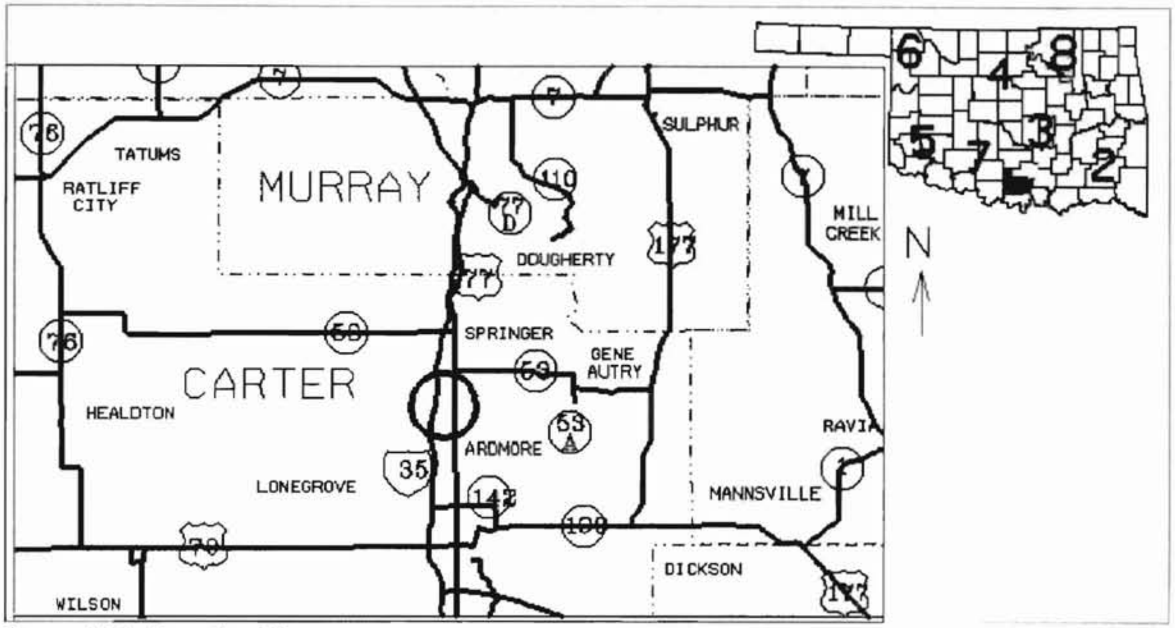


Figure A91. Location Map

Direction of travel of Survey Team: Northbound

Pavement condition is similar to southbound traffic lanes. For the whole length transverse cracks were 0.3 to 0.6 m apart. Crack widths were of the order of 2.00 mm on the average. There was spalling at the cracks. Cracks were generally straight across the pavement. Despite the large overlays at some sections the ride was smooth.

Direction of travel of Survey Team: Southbound

Though there were areas of wider crack spacings, transverse cracks were generally between 0.3 and 0.6 m centers. Cracks widths were in the region of 1.0 to 3.00 mm. There was spalling at the cracks, and a number of longitudinal cracks. There were large sections of asphalt concrete overlay. This prevents an accurate estimate of actual dimensions of the punchout in the CRCP.

Figure A92. Patch at edge of pavement. Transverse and longitudinal cracks intersecting create conditions for punchout.

Figure A93. Full-depth full-width repair on northbound lanes of I-35-1(48) near Arbuckle.

CRCP.34		**Survey date:**	**July 9, 1998**
Division:	**8**	**County:**	**Tulsa**
Project #:	**IM-NHI-44-2(337)**	**Location:**	**SH-33 east of Memorial Dr.**

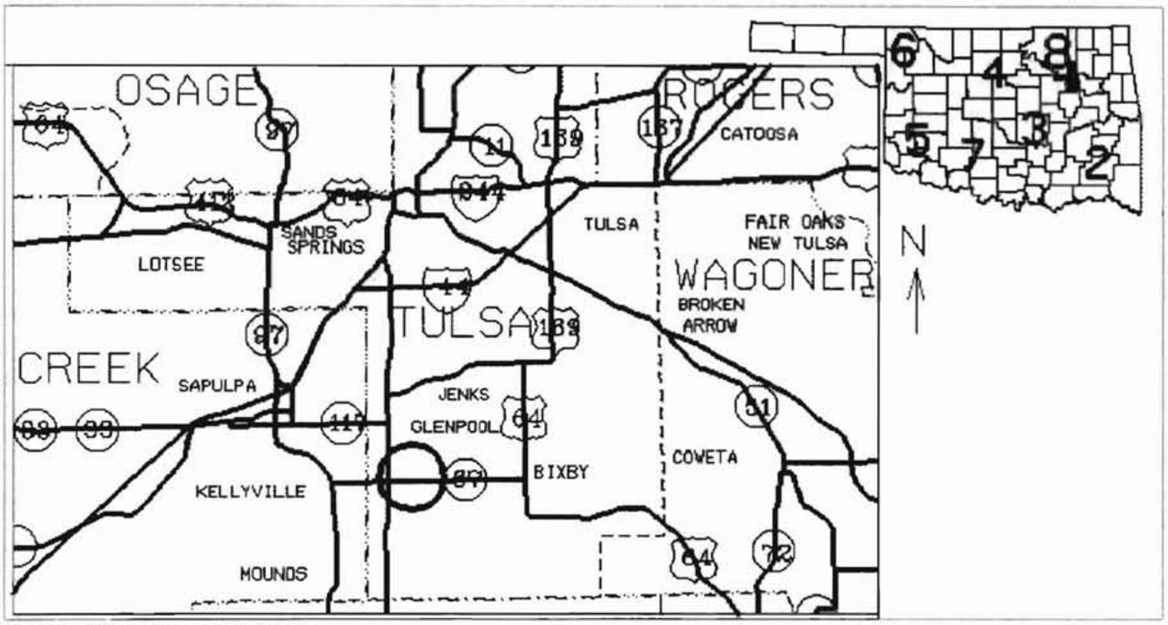


Figure A94. Location Map

Direction of travel of Survey Team: Eastbound

Construction was in progress at the time of survey. Of the pavement laid, the only features observed were the transverse cracks, spaced at 3.6 m centers. The crack widths were 0.30 mm. Erosion of unprotected embankment by water draining from the pavement underdrain is shown in Figure 95. The side of the pavement before backfill is shown in Figure 96.

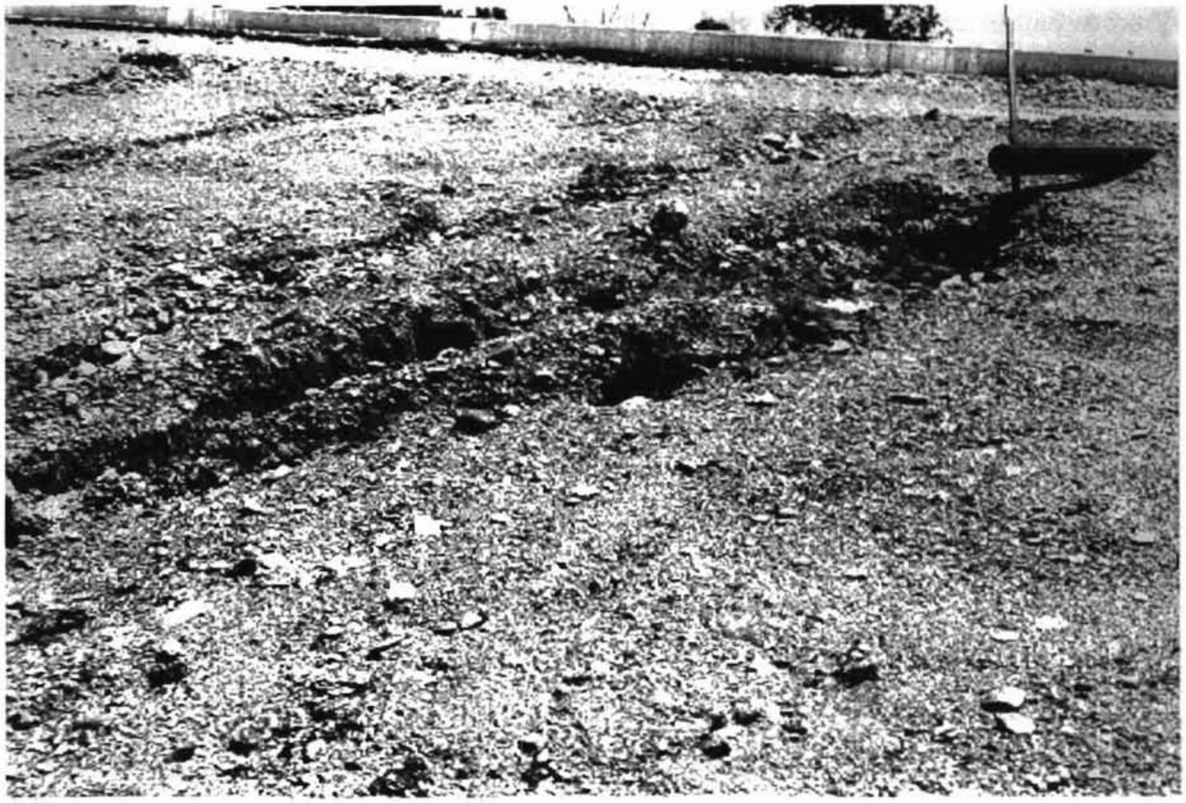


Figure A95. Outlet of drainage under pavement and erosion of embankment.

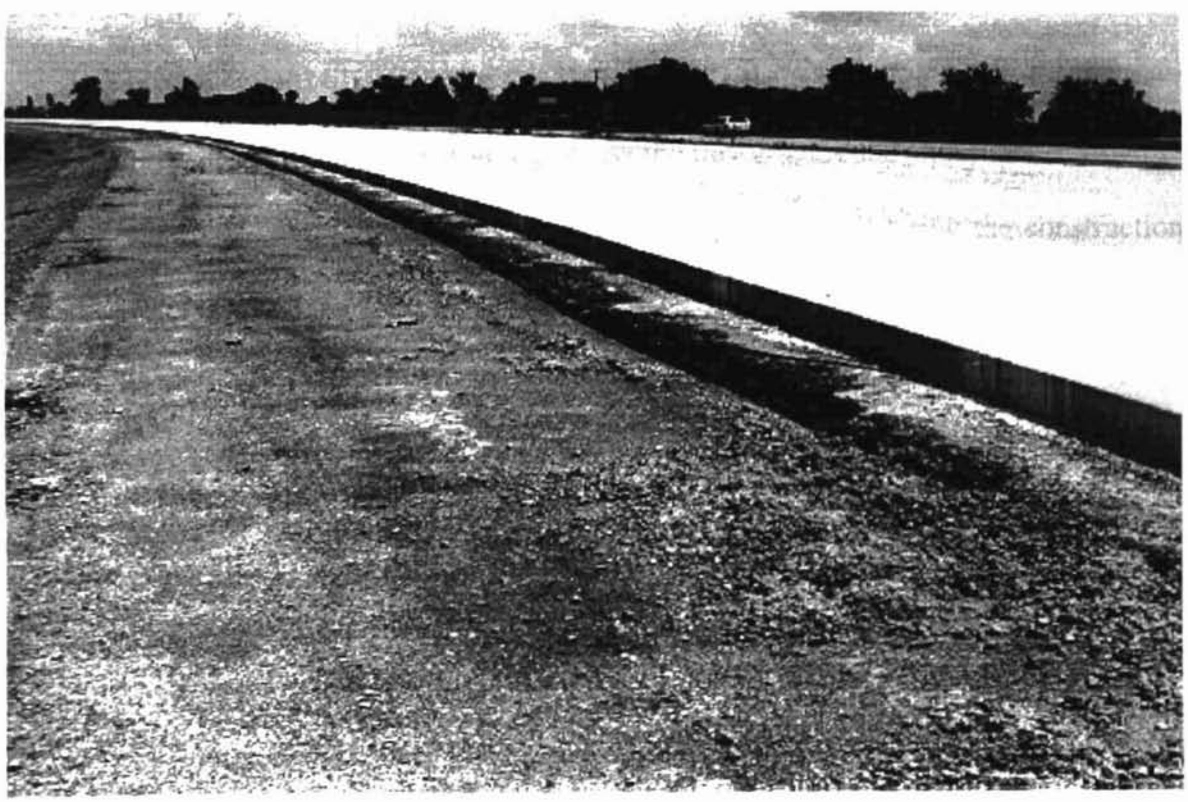


Figure A96. New CRCP constructed at time of survey.

CRCP.35		**Survey date:**	**July 9, 1998**
Division:	**8**	**County:**	**Rogers**
Project #:	**STP-66B(306)**	**Location:**	**US 169 east of Tulsa County line**

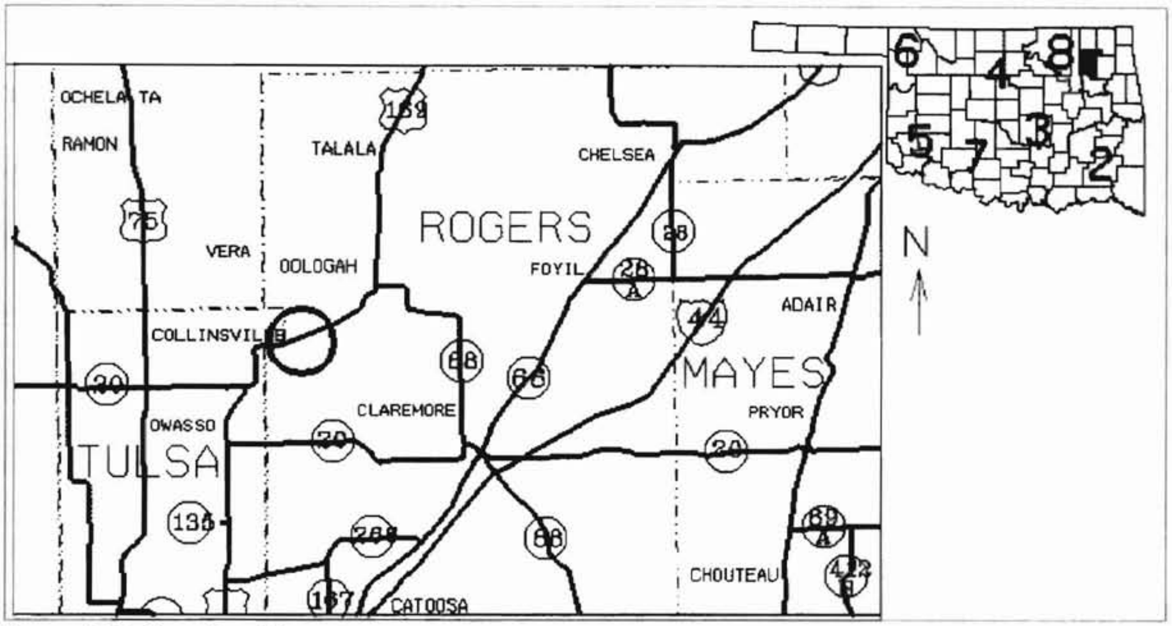


Figure A97. Location Map

Direction of travel of Survey Team: Eastbound

The cracks looked smaller in this direction. There were more Y-cracks and very light spalling. A 10 m long repair going across the travel lanes and shoulders is found in the last section of the project. This appeared to have been done during the construction stage. The pavement is in good shape and the ride was good.

Direction of travel of Survey Team: Westbound

For the first third of the pavement, the transverse cracks were at about 0.9 m. The cracks were generally straight across the pavement. Crack widths were of the order of 0.40 mm. There were a few Y-cracking, no curved cracks and no spalling at the cracks.

The middle third of the length looked like a different contractor's work. The transverse cracks were 0.6 to 0.9 m centers. The crack widths were wider than in the other sections – about 0.50 to 0.80 mm. There were clustered crack patterns and some Y-cracks but no curved cracks.

There were no longitudinal cracks and no punchouts. There was one repair in middle section, approximately 10 m long across the two traffic lanes and shoulders. It could not be determined whether this repair was done at the time of construction. The terminal joints were not damaged. Construction joints were all good. The drive was excellent.

The occasional occurrence of curved cracks in Division 8 is shown in Figure 98. Figure 99 is a typical view of CRCP condition in Division 8.

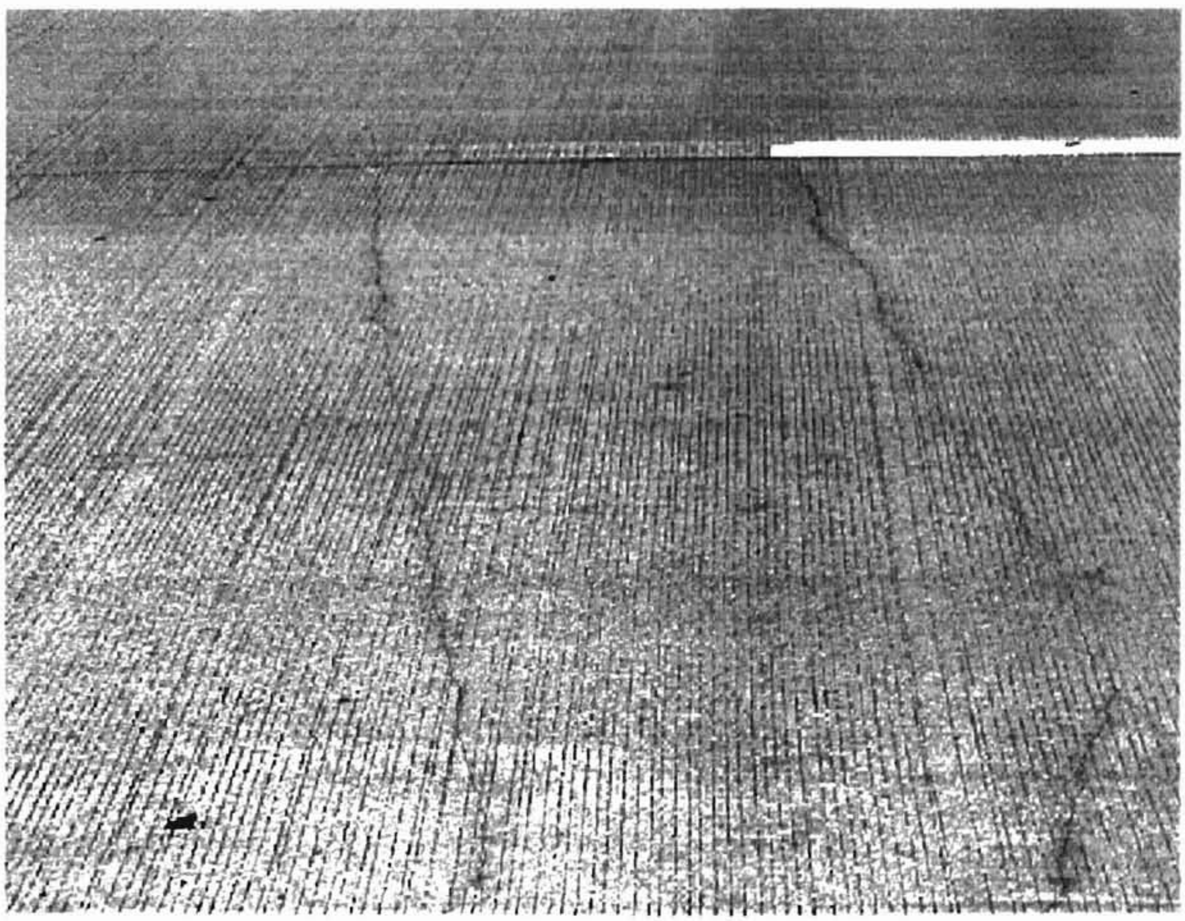


Figure A98. Typical pavement condition in Division 8.

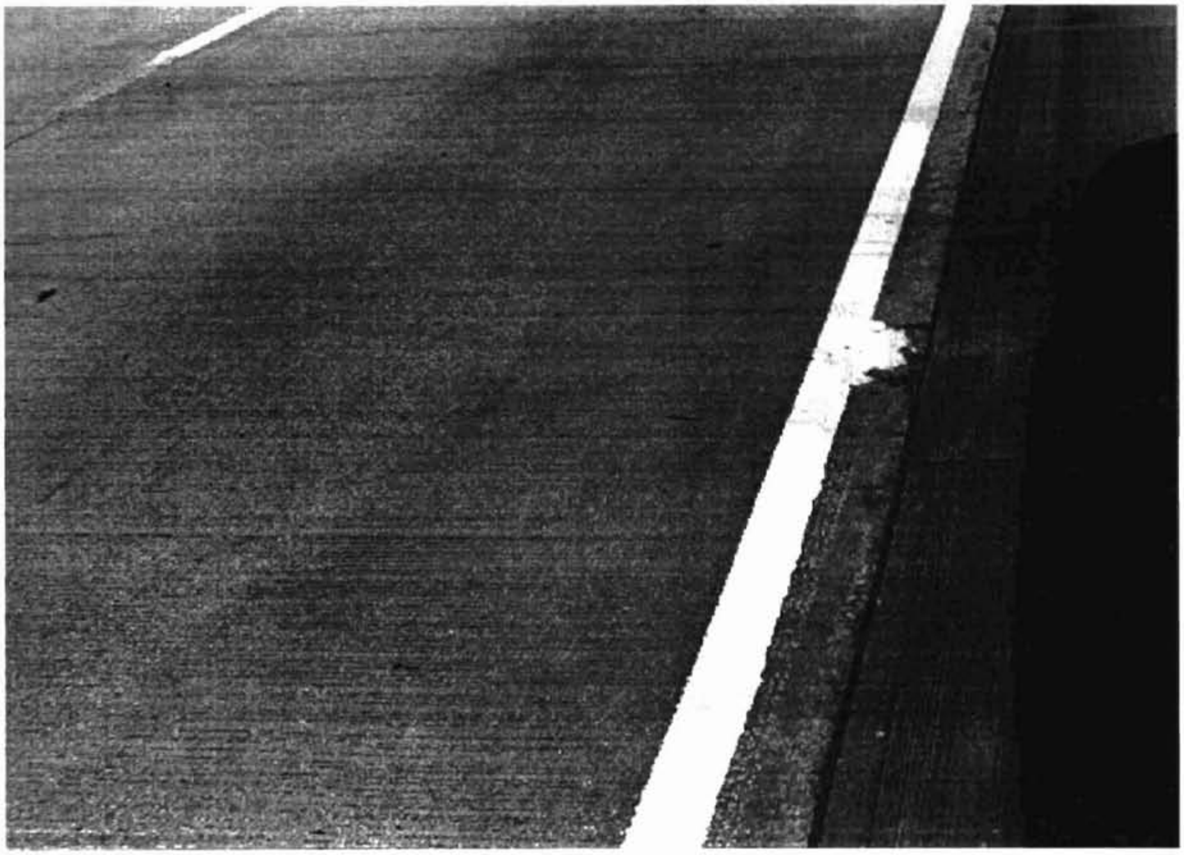


Figure A99. Typical view of transverse cracks in Division 8.

CRCP.36		**Survey date:**	**July 9, 1998**
Division:	**8**	**County:**	**Mayes**
Project #:	**DPI-204(16)**	**Location:**	**SH-20 east of Rogers County**

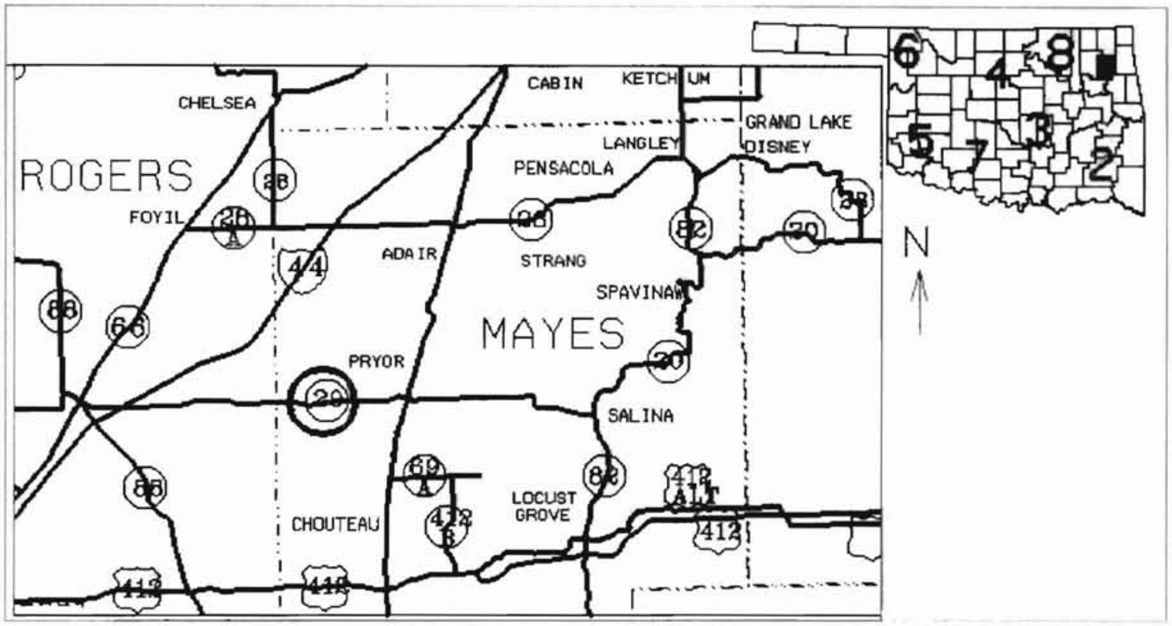


Figure A100. Location Map

Direction of travel of Survey Team: Eastbound

Transverse Crack spacing was around 2.3 m. Crack widths were 0.30 to 0.80 mm. Crack widths were finer at the central third of the project. There were no longitudinal cracks, no punchouts, and no repairs. The ride was good.

Direction of travel of Survey Team: Westbound

This is similar to the eastbound section. There were no punchouts, no repairs, and no longitudinal cracks. The ride was good.

CRCP.37		**Survey date:**	**July 9, 1998**
Division:	**8**	**County:**	**Mayes**
Project #:	**DSB-49B(290)**	**Location:**	**SH-20 near Pryor**

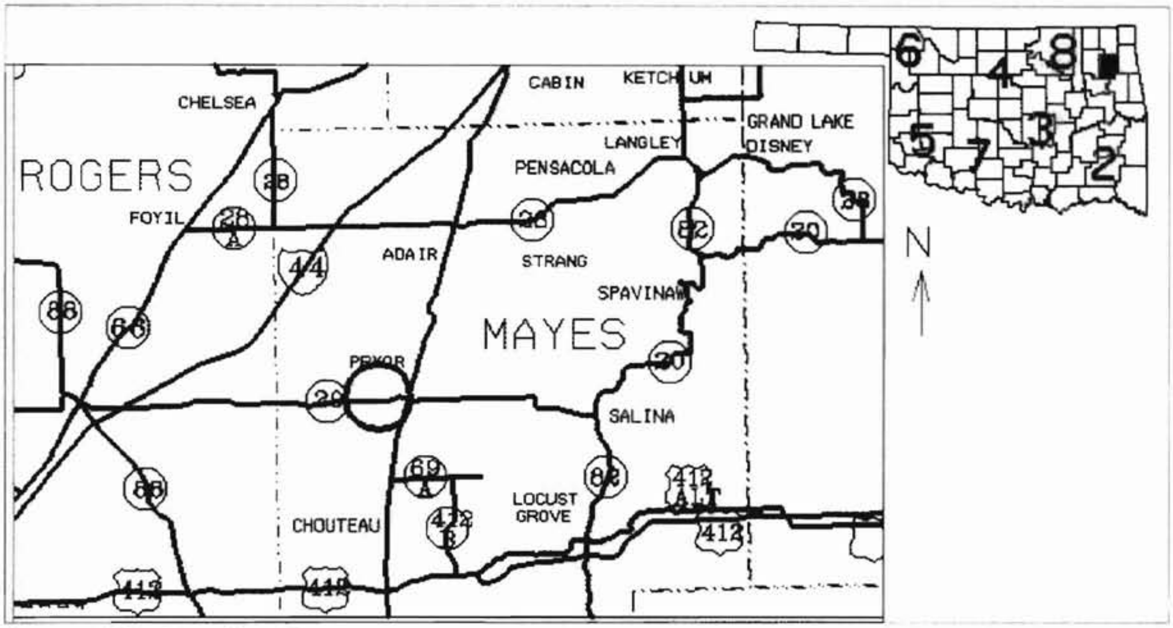


Figure A101. Location Map

Direction of travel of Survey Team: Eastbound

This project is a continuation of Federal Aid Project # DPI-204(16) described above. The qualities of the two projects look the same and they show similar characteristics. Transverse cracks were spaced at 2.3-m centers for a large portion of the project. Crack widths were 0.30 to 0.80 mm. The central third of this contract has crack widths of under 0.50 mm. The pavement provides an excellent riding surface.

Direction of travel of Survey Team: Westbound

The quality of work looks good and the characteristics shown is similar to the eastbound section.

CRCP.38		**Survey date:**	**July 9, 1998**
Division:	**8**	**County:**	**Mayes**
Project #:	**F-593(252)**	**Location:**	**US-69 near Pryor Creek**

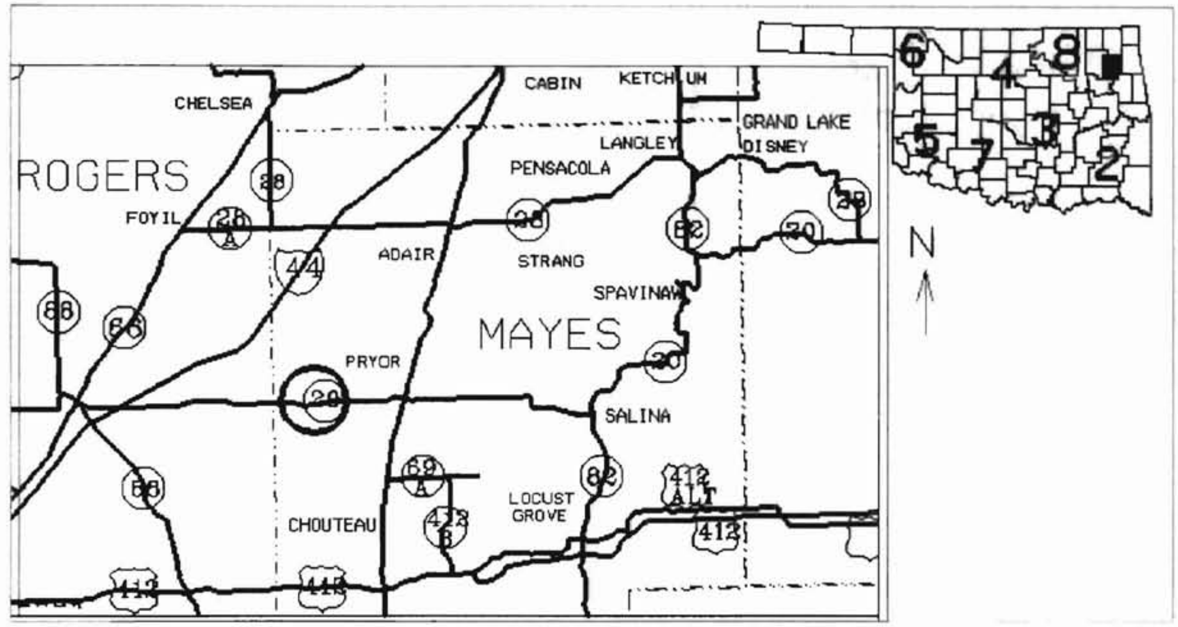


Figure A102. Location Map

This project, as a whole, represents the typical characteristic of a CRCP. Transverse cracks were 0.6 to 1.5 m centers. Crack widths were 0.50 to 1.00 mm. There were some cluster type cracks and some Y-cracking. This has wide flange at the ends with light spalling around the structural steel beam. The terminal joints were not damaged in any way. Construction joints were all good. There were no signs of repairs due to construction defects. The pavement provided an excellent riding surface.

CRCP.39		**Survey date:**	**July 9, 1998**
Division:	**8**	**County:**	**Rogers and Mayes**
Project #:	**F-194(45)**	**Location:**	**SH-33 between Inola & Chouteau**

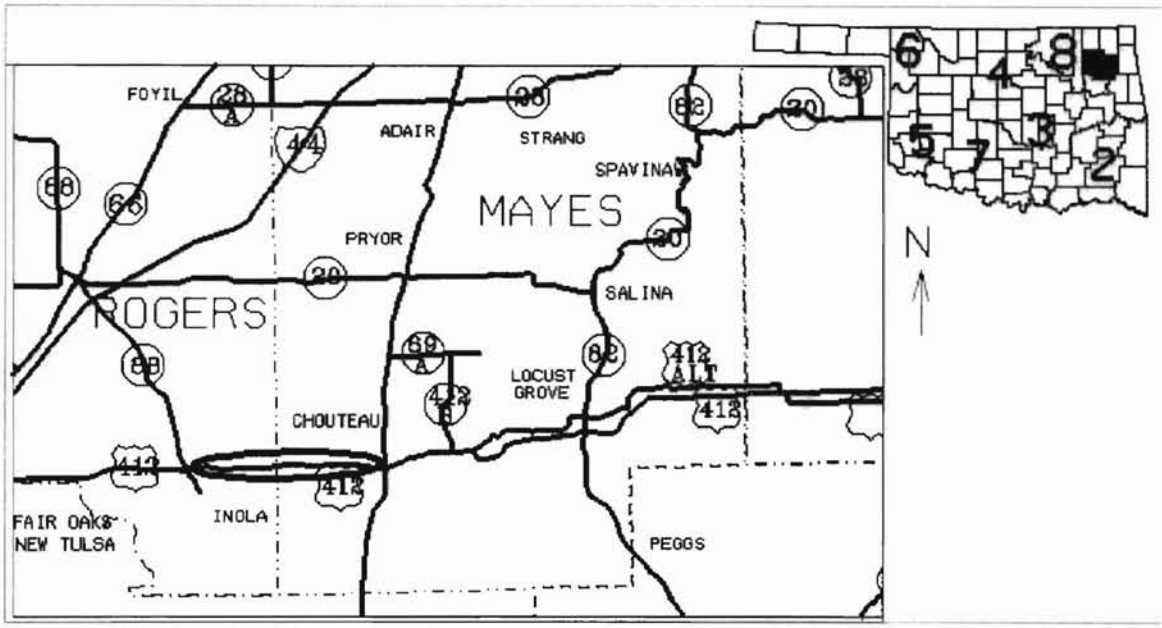


Figure A103. Location Map

Transverse crack spacing were 0.9 to 2.0 m centers. Crack widths were less than 0.50 mm. The crack widths at the cross-overs were about 1.00 mm. Some Y-cracking is present at a few places. There is light spalling around some cracks, but no longitudinal cracks and no other defects. The ride was good.

CRCP.40		**Survey date:**	**July 9, 1998**
Division:	**8**	**County:**	**Mayes**
Project #:	**F-398(35)**	**Location:**	**SH-33 near Chouteau**

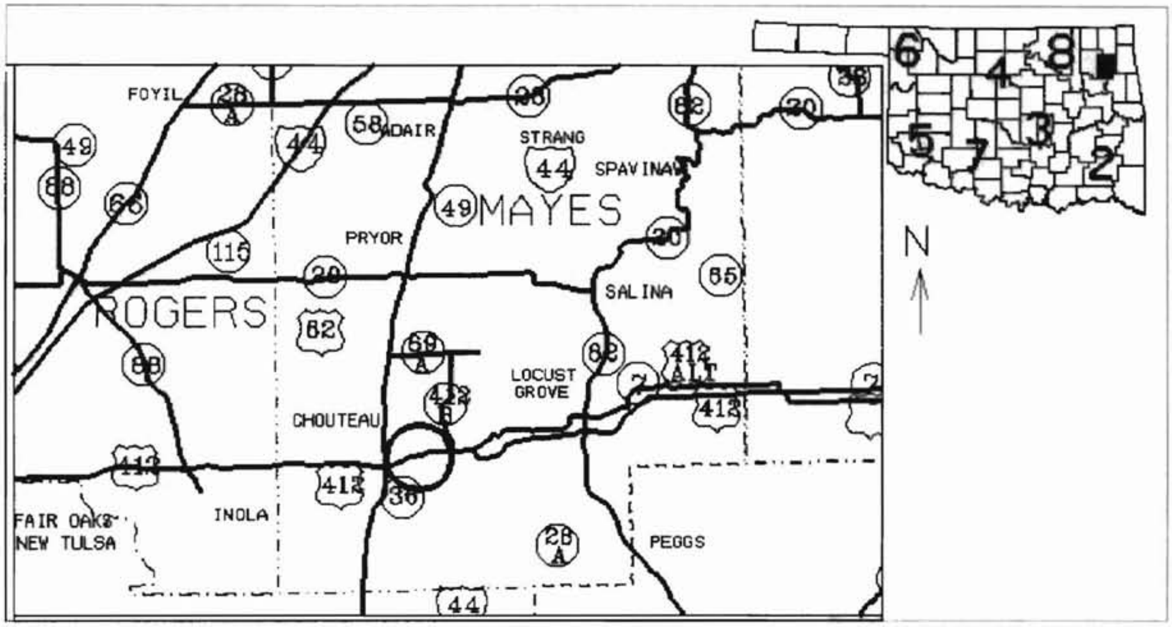


Figure A104. Location Map

This stretch of CRCP follows Federal Aid Project # F-194(45). The transverse crack spacing were 0.9 to 2.0 m centers. Crack widths were less than 0.50 mm. The crack widths at the cross-overs were about 1.00 mm. Some Y-cracking is present at a few places. There was light spalling around some cracks. There were no longitudinal cracks or other defects. The pavement is good and the ride was excellent.

CRCP.41		**Survey date:**	**July 10, 1998**
Division:	**8**	**County:**	**Rogers**
Project #:	**MAF-194(35)**	**Location:**	**SH-33**

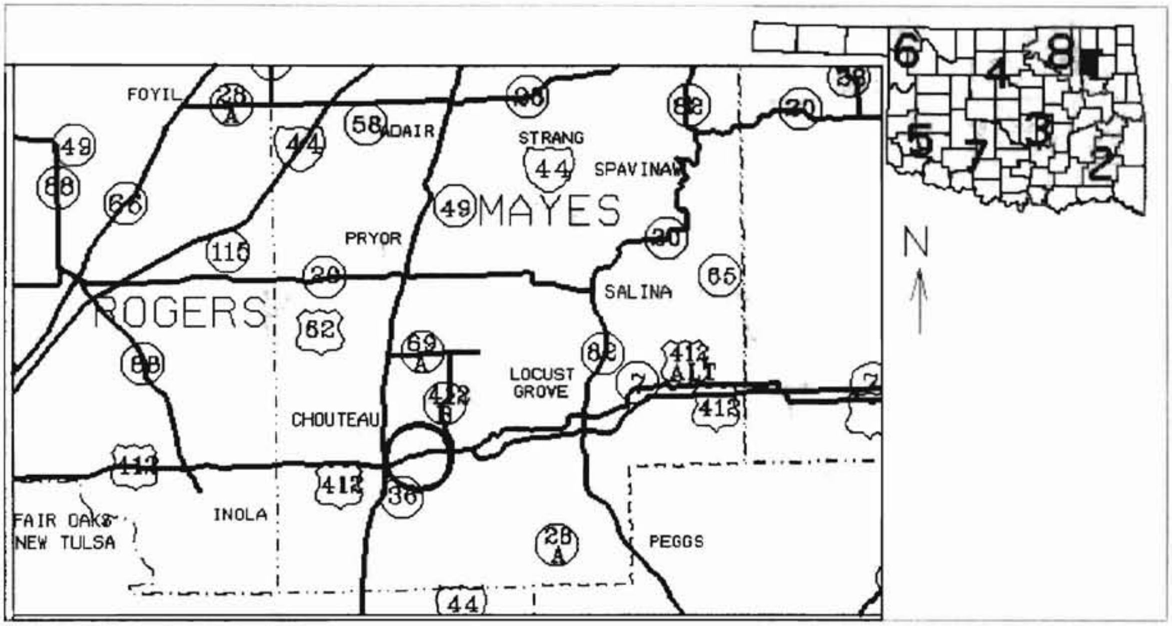


Figure A105. Location Map

This is part of the stretch of CRCP on SH-33. This section is similar to project numbers F-194(45) and F-398(35), both on state highway SH-33. Transverse crack spacing were 0.9 to 2.0 m centers. Crack widths were less than 0.50 mm. The crack widths at the cross-overs were about 1.00 mm. Some Y-cracking is present at a few places. There was light spalling around some cracks. There were no longitudinal cracks or other defects. The pavement provided an excellent riding surface.

CRCP.42		**Survey date:**	**July 10, 1998**
Division:	**8**	**County:**	**Tulsa**
Project #:	**MAF-521(075)**	**Location:**	**US-169 north of 71st St.**

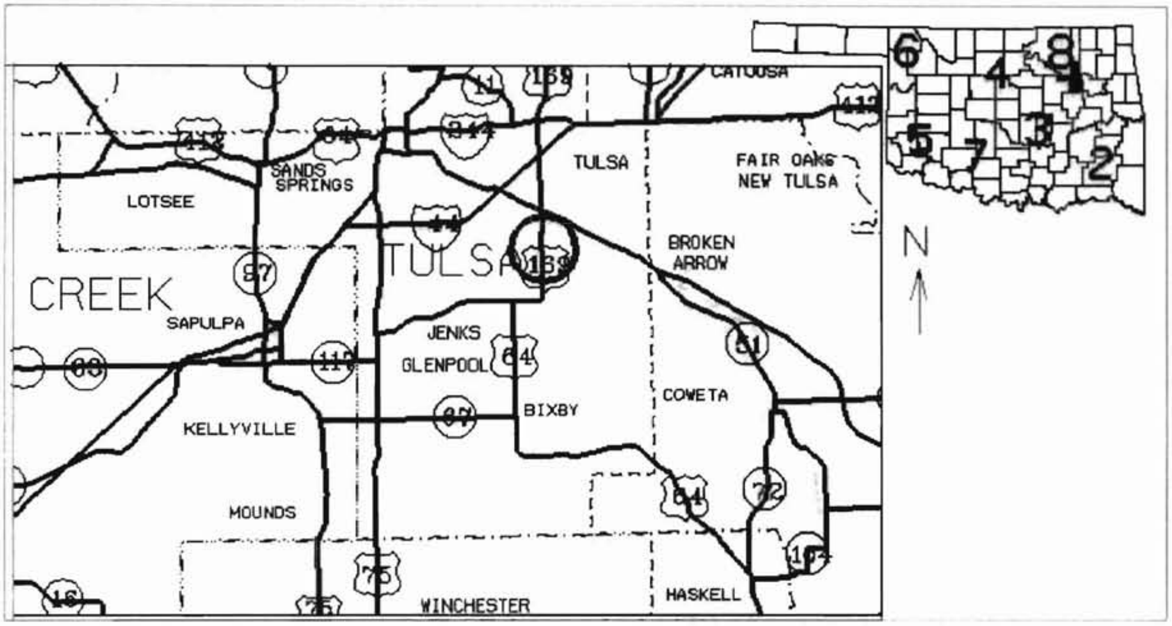


Figure A106. Location Map

Transverse cracks were at 1.5 m centers. Crack widths were about 0.33 mm. This is the condition for the whole project. There were no punchouts and no longitudinal cracks. The ride is excellent.

CRCP.43		**Survey date:**	**July 10, 1998**

CRCP.43		**Survey date:**	**July 10, 1998**
Division:	**8**	**County:**	**Tulsa**
Project #:	**STPY-72B(405)**	**Location:**	**SH-67 West of Yale Ave**

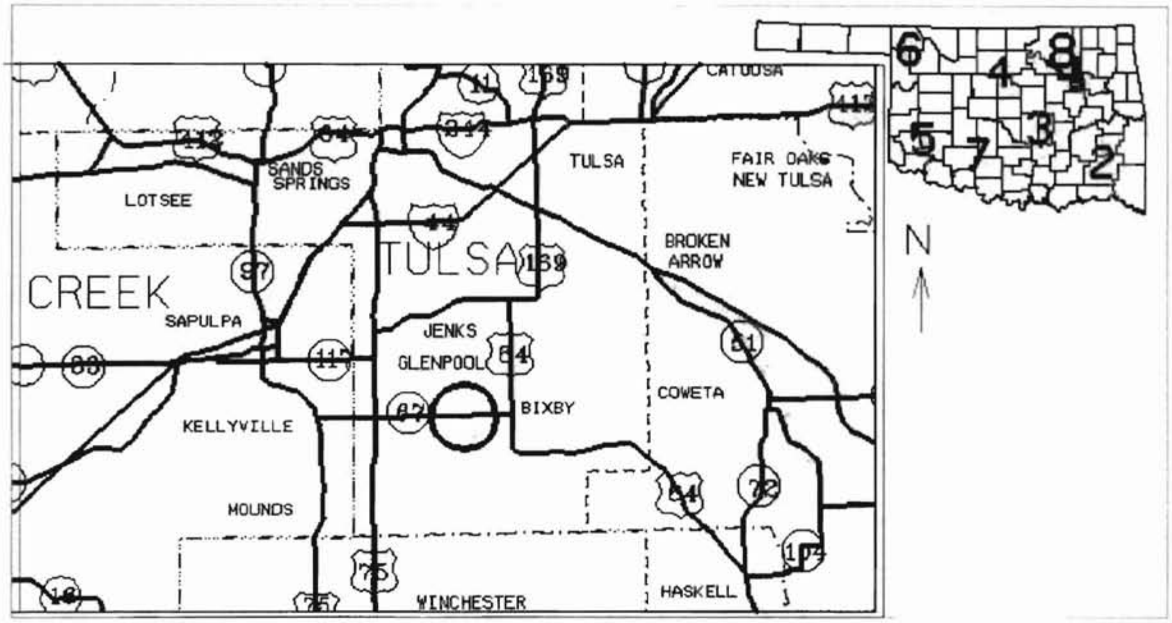


Figure A107. Location Map

Direction of travel of Survey Team: Eastbound

This direction has characteristics very similar to the westbound lanes.

Direction of travel of Survey Team: Westbound

The transverse cracks were at 1.0 to 1.5 m spacing and the crack widths were 0.25 to 0.80 mm. There were no defects in the pavement. The ride was good.

CRCP.44		**Survey date:**	**July 10, 1998**
Division:	**8**	**County:**	**Tulsa**
Project #:	**STPY-72C(404)**	**Location:**	**SH-67 (Peoria Av – Harvard Av)**

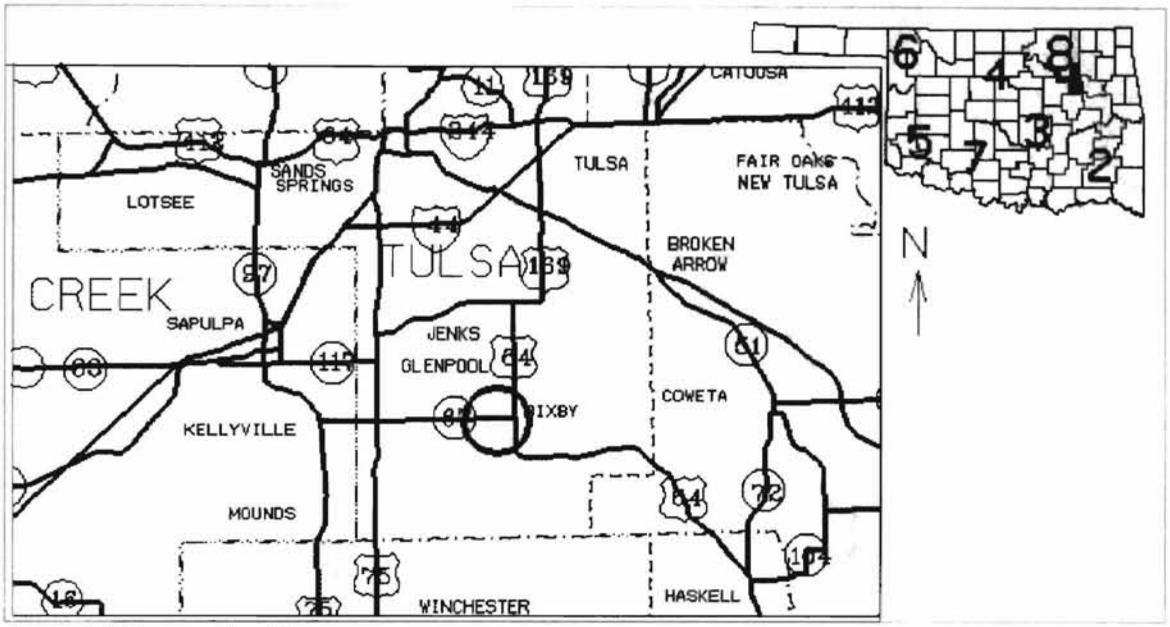


Figure A108. Location Map

Direction of travel of Survey Team: Eastbound

The transverse crack spacings were 1.0 to 1.5 m. Crack widths were about 0.25 mm at the first third but were wider - 0.25 to 0.80 mm with light spalling for the central and last third section of the project. There were a few Y-cracks. However, there were no longitudinal cracks and no failures. The ride in both directions was good.

Direction of travel of Survey Team: Westbound

The transverse crack spacings for this project were 1.0 to 1.5 m. Crack widths were about 1.00-mm in the first two thirds of the way, with light spalling at the cracks. The crack widths at the last third in this direction were finer, – about 0.25 mm. There were a few Y-cracks, but no longitudinal cracks.

CRCP.45
Division: 8
Project #: F-15(218)

Survey date: July 10, 1998
County: Tulsa
Location: US-75 north of Lake Yahola

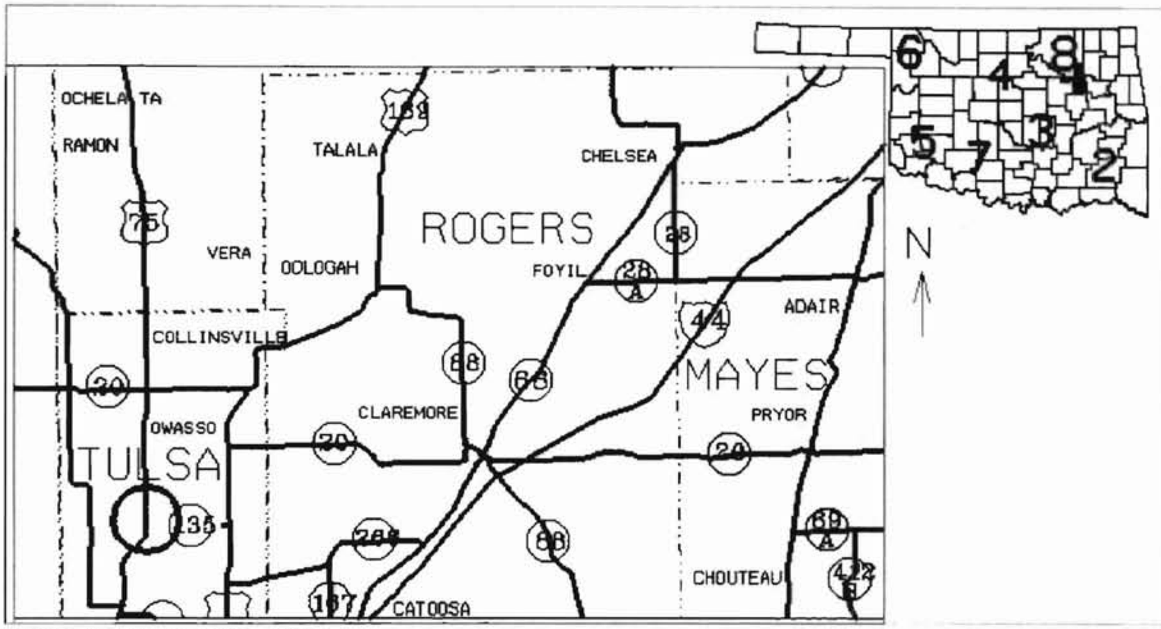


Figure A109. Location Map

Direction of travel of Survey Team: Northbound

Transverse cracks were at 0.3 to 1.0 m spacing. The crack widths were 0.30 to 0.60 mm. There was no Y-cracking on the whole project. It is worth noting that the shoulders were not cut as is done on the other projects. The CRCP provided an excellent riding surface. The general condition of CRCPs in Division 8 is shown in Figure A110.

A condition, which is seen on some CRCPs, is bleeding of water through the cracks in the pavement. This results in some discoloration at the cracks and joints. Discoloration of transverse and longitudinal cracks is seen in Figure 111.

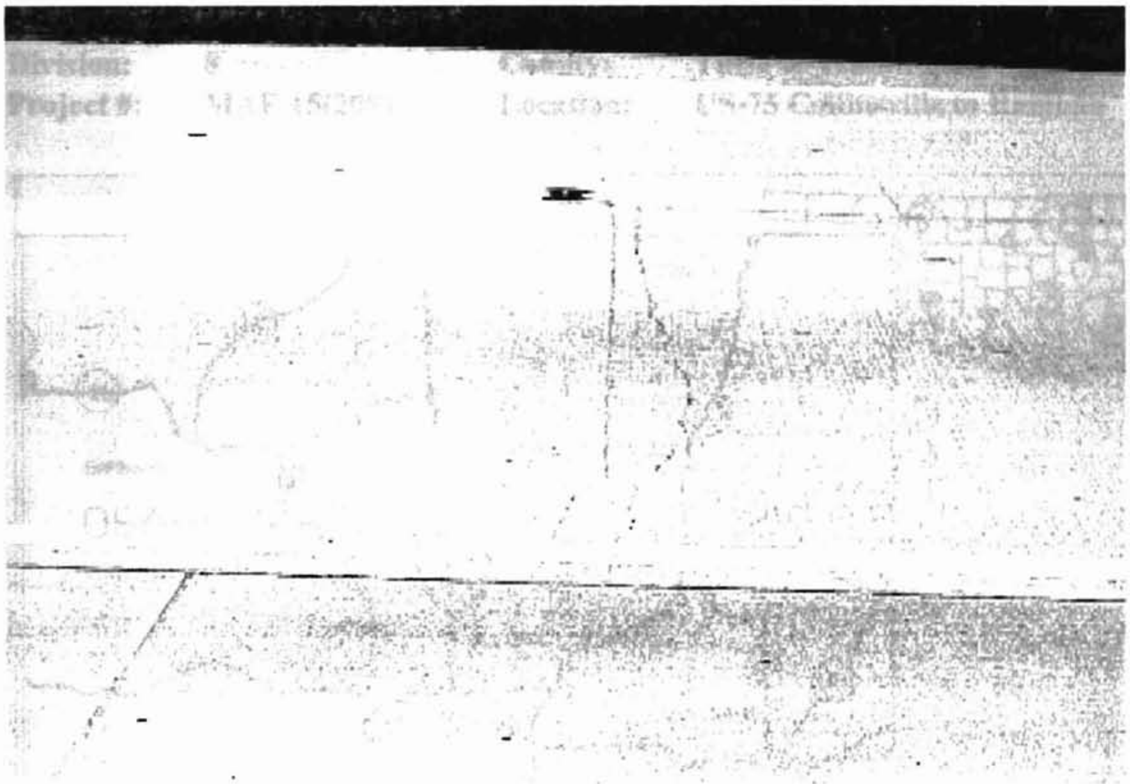


Figure A110. Typical view of pavements in Division 8.

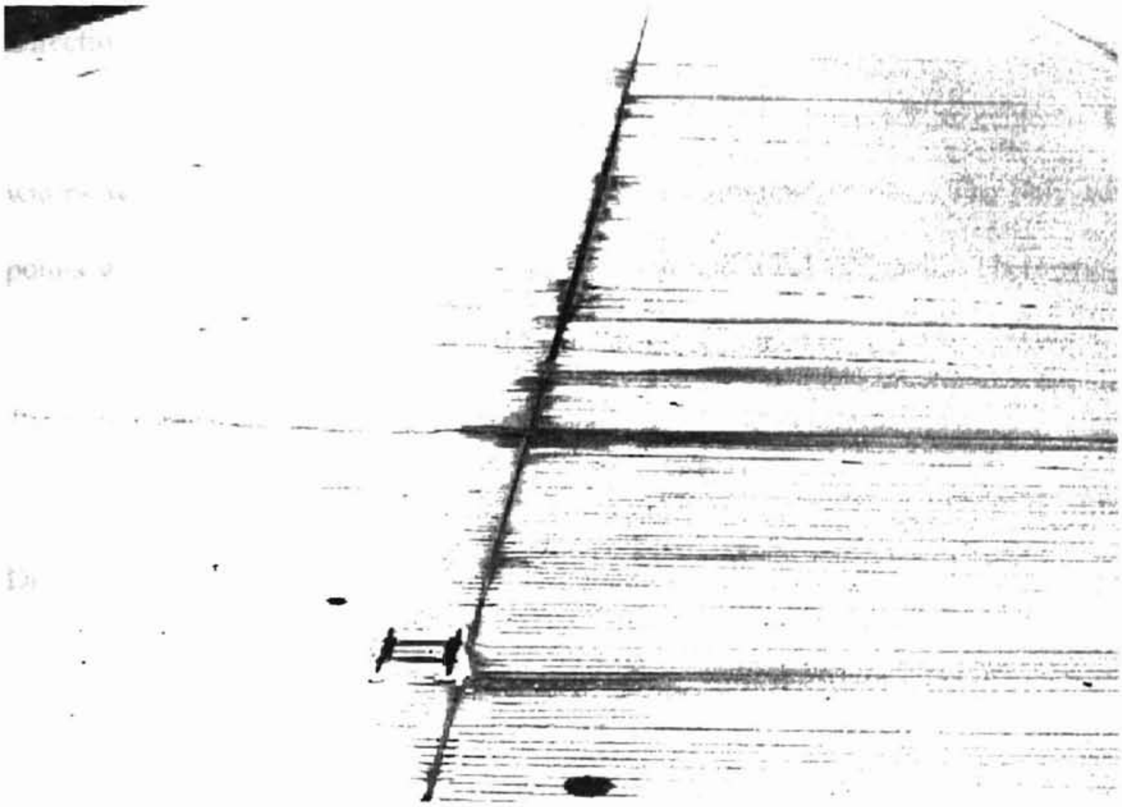


Figure A111. Discoloration at transverse cracks.

CRCP.46		**Survey date:**	**July 10, 1998**

CRCP.46		**Survey date:**	**July 10, 1998**
Division:	**8**	**County:**	**Tulsa & Washington**
Project #:	**MAF-15(209)**	**Location:**	**US-75 Collinsville to Ramona**

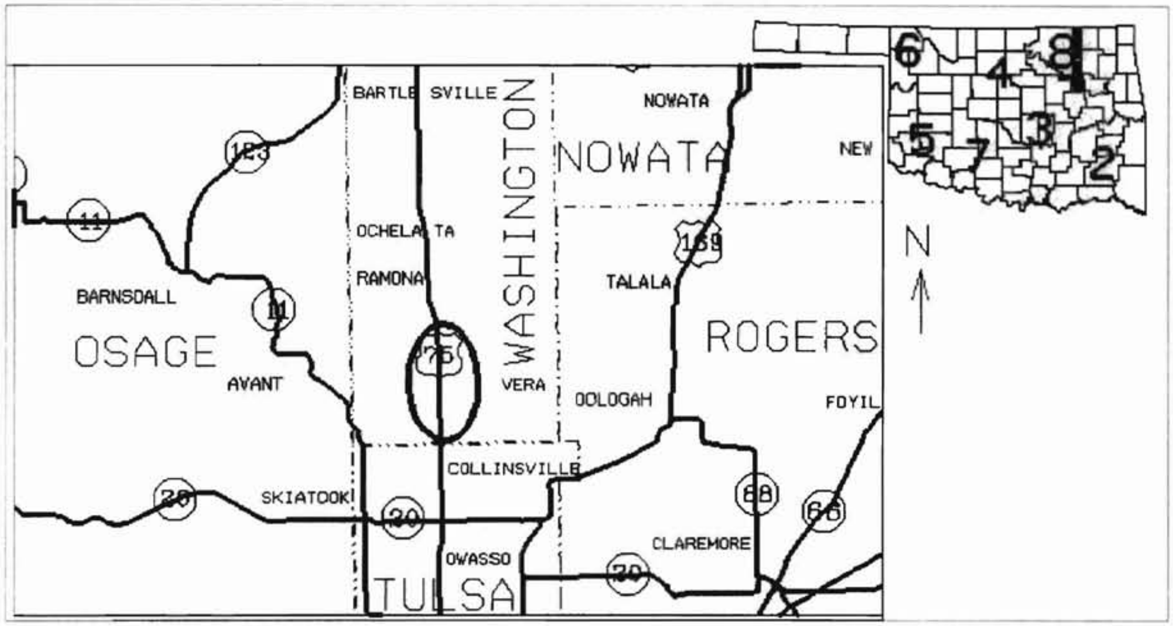


Figure A112. Location Map

Direction of travel of Survey Team: Northbound

Transverse cracks were generally widely spaced, about 4.5 m centers. Crack widths were 0.30 to 0.70 mm. There were no longitudinal cracks. The only adverse points were a 0.2 m^2 punchout filled with asphalt and a 0.1 m^2 spall. There was light water bleeding at the cracks evidenced by the discoloration at the cracks.

The CRCP provided an excellent riding surface and driver comfort.

Direction of travel of Survey Team: Southbound

The pavement in this direction is not CRC.

CRCP.47		**Survey date:**	**July 10, 1998**
Division:	**8**	**County:**	**Washington**
Project #:	**MAF-15(211)**	**Location:**	**US-75 near Ramona**

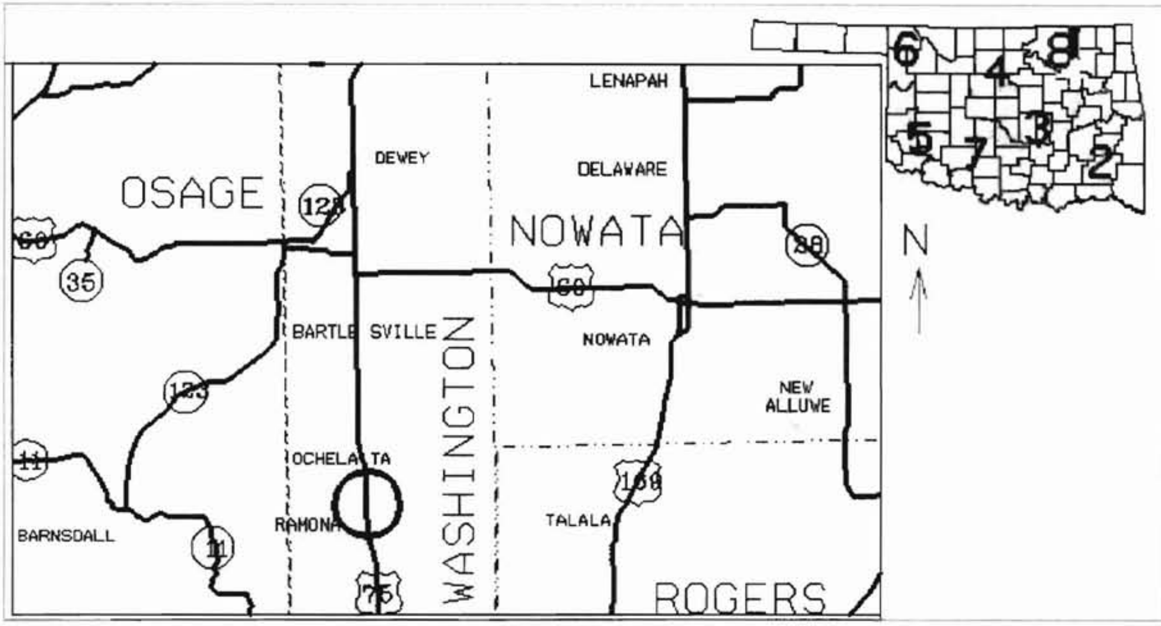


Figure A113. Location Map

Direction of travel of Survey Team: Northbound

The spacing of the transverse crack was in the general range of 0.6 to 2.0 m. Crack widths were 0.20 to 0.60 mm. A transverse construction joint was defective. The length affected is about 0.5 m. It is at construction joints that problems are most likely to occur. Other than the above joint, there were no longitudinal cracks and no failures. The CRCP provided an excellent riding surface for driver comfort.

Direction of travel of Survey Team: Southbound

The transverse crack spacing and widths were similar to the northbound lanes. There was water bleeding from the longitudinal joint between lanes.

CRCP.48 | **Survey date:** **July 10, 1998**

Division: **8** | **County:** **Washington**

Project #: **MAF-15(213)** | **Location:** **US-75 near Ochelata**

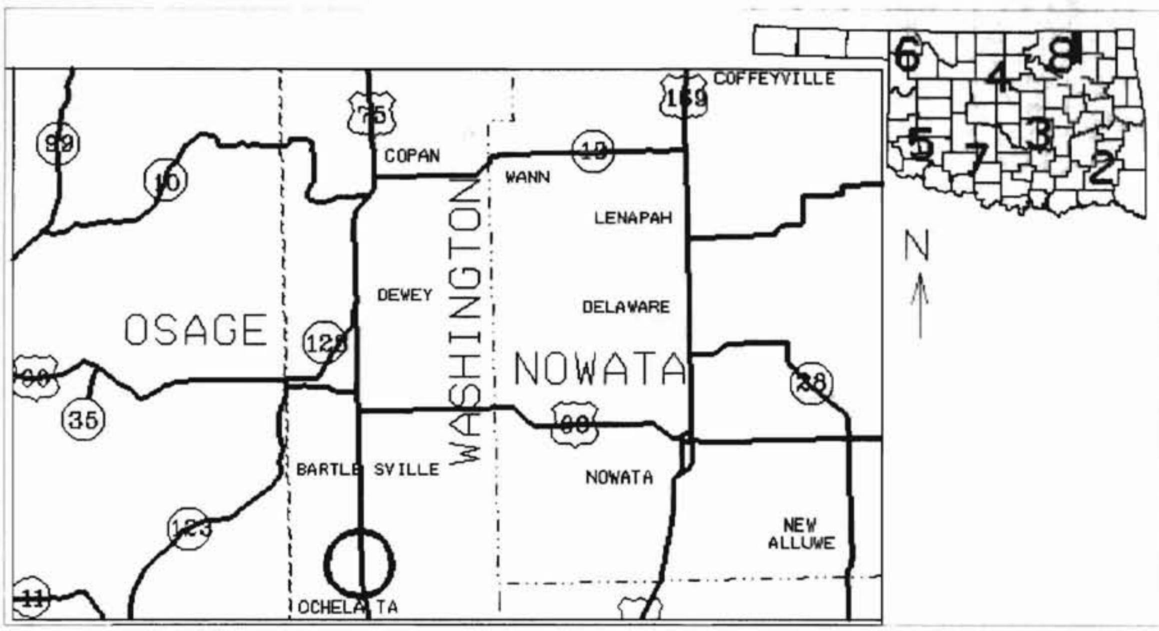


Figure A114. Location Map

Direction of travel of Survey Team: Northbound

Transverse crack spacings were 0.6 to 1.5 m centers. Crack widths were 0.20 to 0.60 mm. There has been some bleeding at the cracks. There was some Y-cracking also. The ride was excellent.

Direction of travel of Survey Team: Southbound

Similar to the northbound lane but there were some spalling at the cracks.

CRCP.49		**Survey date:**	**July 10, 1998**
Division:	**8**	**County:**	**Washington**
Project #:	**NH-481(69)**	**Location:**	**US-75**

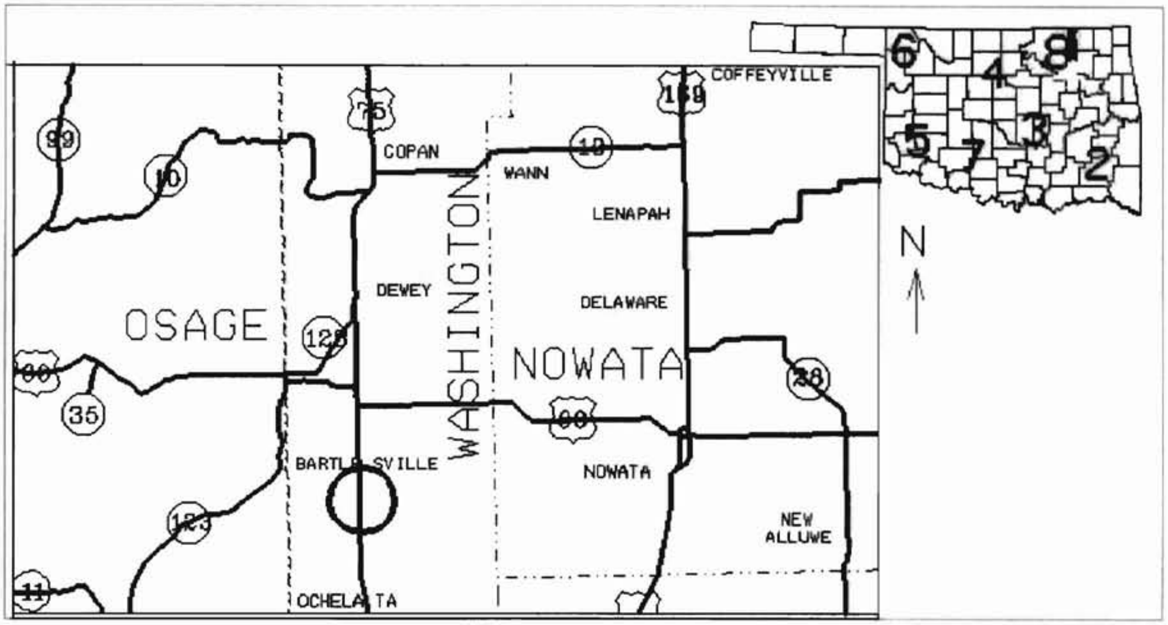


Figure A115. Location Map

Direction of travel of Survey Team: Northbound

This is a very nice project. The cracks were barely visible. Transverse cracks were 1.5 to 2.0 m centers. Crack widths were less than 0.50 mm. The turning lanes were of jointed concrete pavement. There were no defects in the whole length. The ride was very smooth and comfortable.

Direction of travel of Survey Team: Southbound

This is similar to the northbound lanes.

CRCP.50		**Survey date:**	**July 10, 1998**
Division:	**8**	**County:**	**Washington**
Project #:	**NH-14N(013)**	**Location:**	**US-75 near Copan**

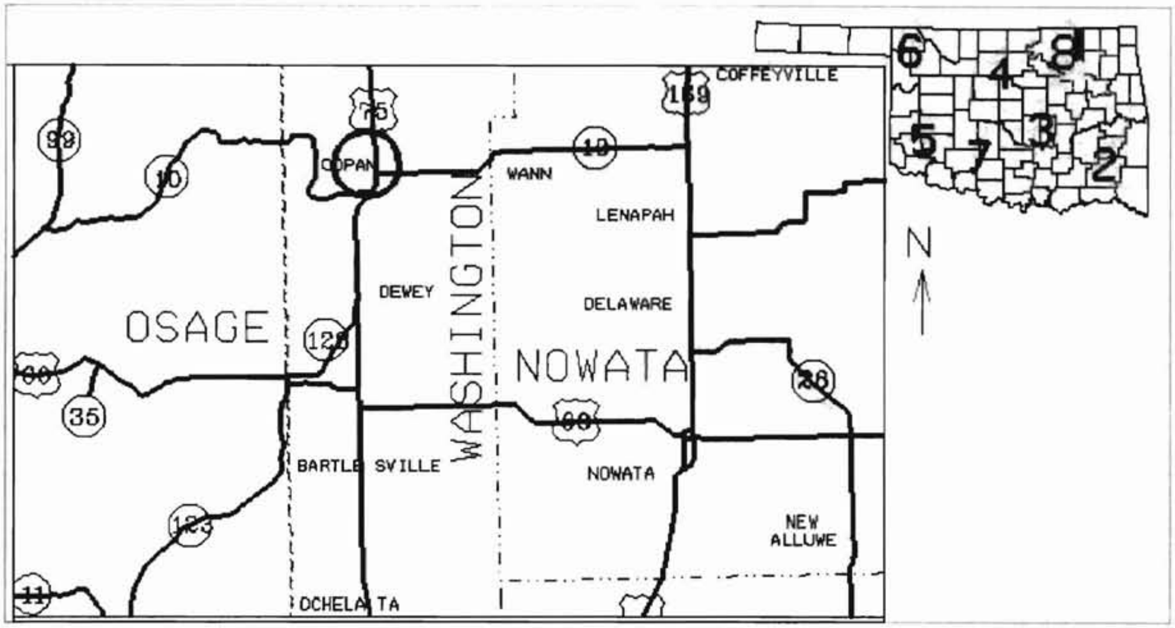


Figure A116. Location Map

Direction of travel of Survey Team: Northbound

This direction has asphalt concrete pavement.

Direction of travel of Survey Team: Southbound

This project had cracks that were barely visible. Transverse cracks were generally 1.5-m centers. Crack widths were 0.20 to 0.40 mm. The turning lanes here were made of jointed concrete pavement. There was no problem with this project. The ride was very good.

CRCP.51		**Survey date:**	**July 10, 1998**
Division:	**8**	**County:**	**Creek and Tulsa**
Project #:	**IR-44-2(328) 221**	**Location:**	**I-44 near Creek/Tulsa County line**

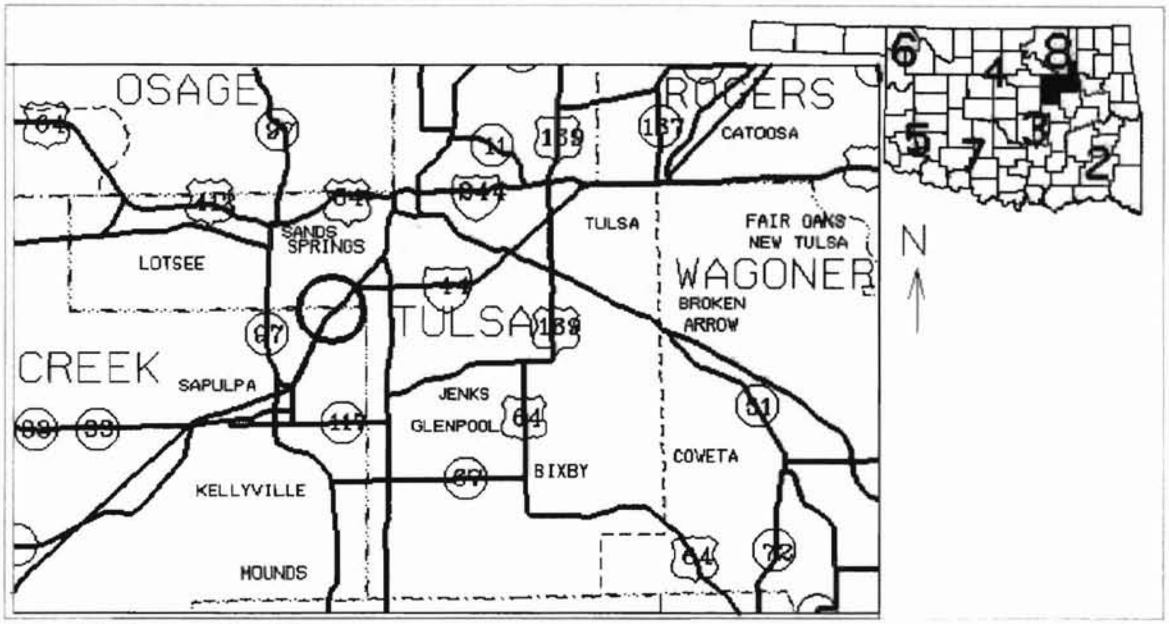


Figure A117. Location Map

Direction of travel of Survey Team: Eastbound and Westbound

This is a very busy road and a detailed survey was not safe under the traffic conditions. The drive-through was at about ninety km/h. There were no defects such as punchouts, large spalling, construction joint deterioration or patches noticed in any section of the project. The ride was excellent and there did not seem to be any problem at any section of the roadway in both directions of travel.

CRCP.52		**Survey date:**	**July 10, 1998**
Division:	**8**	**County:**	**Tulsa**
Project #:	**I-244-2(101)**	**Location:**	**I-244**

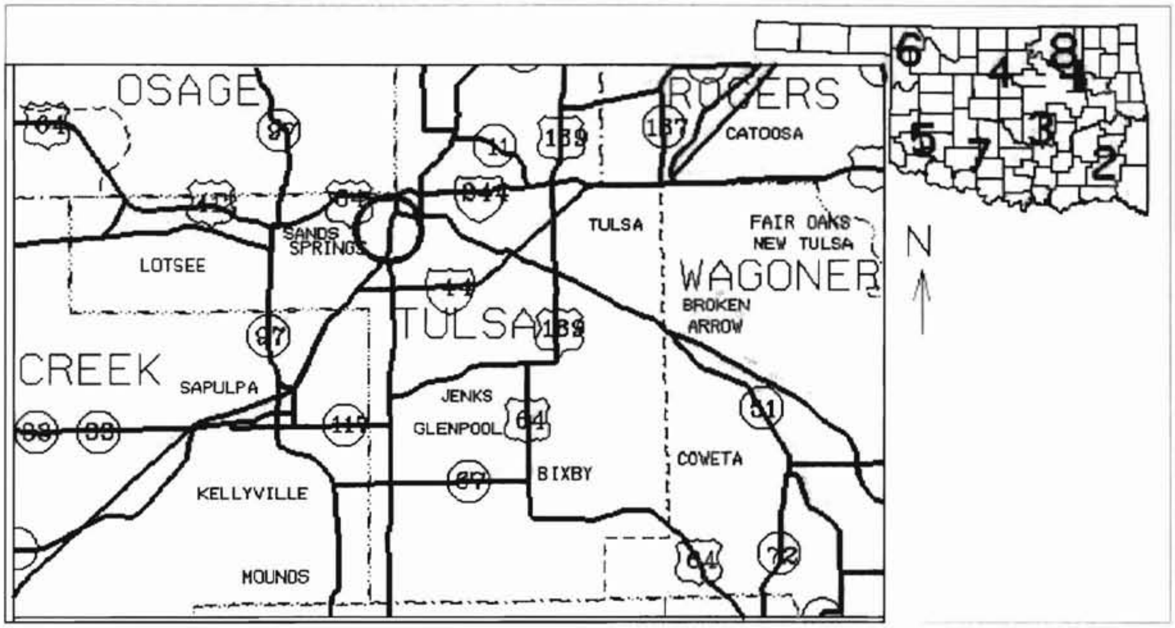


Figure A118. Location Map

This is also a very busy road. It was not safe to do any inspection from the shoulder as was done with the others. The drive-through was at about ninety km/h. There were no defects such as punchouts, large spalling, construction joint deterioration or patches noticed in any section of the project. The ride was excellent in both directions of travel.

CRCP.53		**Survey date:**	**July 10, 1998**
Division:	**8**	**County:**	**Tulsa**
Project #:	**I-244-2(108)**	**Location:**	**I-244**

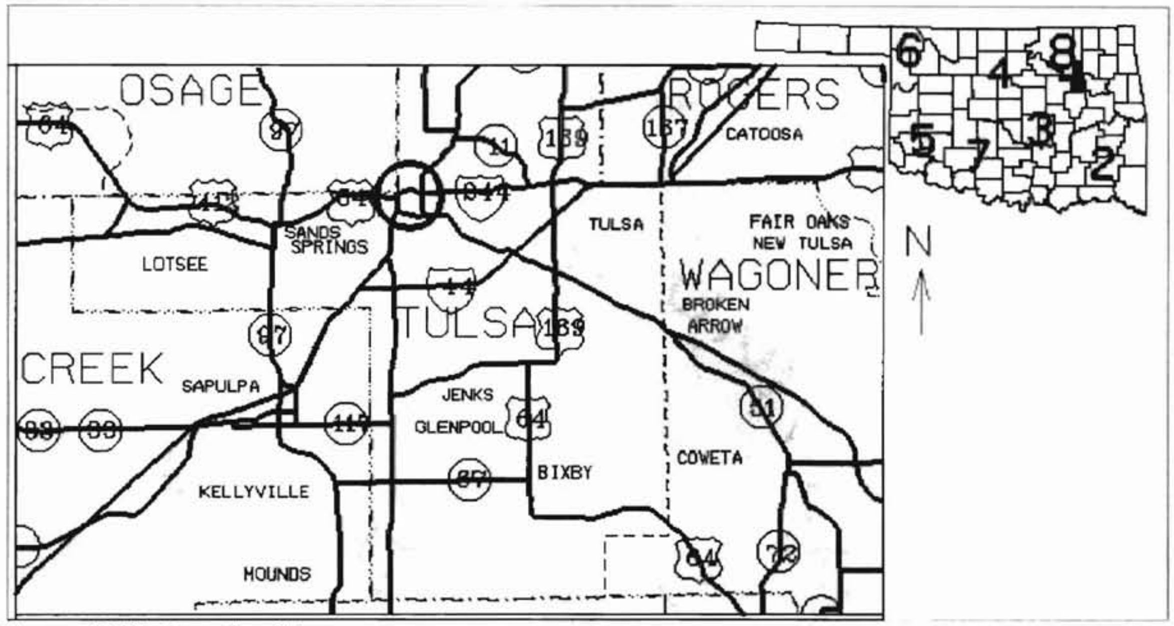


Figure A119. Location Map

As described in projects IR-44-2(328)221 and I-244-2(101), this is in the center of an urban district and is a very busy road with traffic conditions unsafe for detailed survey. There was only a quick drive through the section, looking for any defects such as punchouts, faults, joint failures, or longitudinal cracks. There were no defects such as punchouts, large spalling, construction joint deterioration, and no patches noticed in any section of the project. The ride was good, and there did not seem to be any problem at any section of the roadway in both directions of travel.

There is normally a failure at the joint of CRCPs and asphalt concrete. The condition is seen in Figure A120. Figure A121 is the view of general condition of CRCPs in Division 8.

Figure A120. Patch at joint of CRC and asphalt pavements.

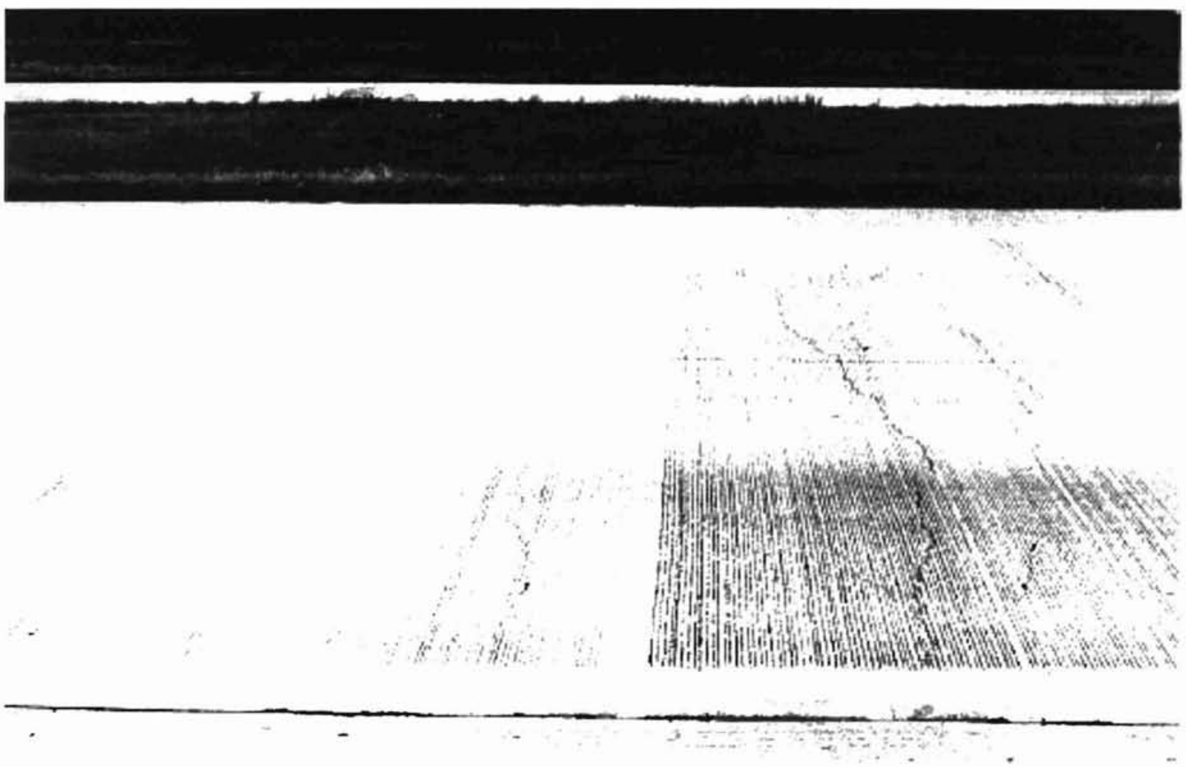


Figure A121. Typical CRCP in Division 8.

APPENDIX B

Appendix B Data Collection Sheets

CRCP Site Visit Notes

Location:
Project Number:
Direction:

Date:
Time:

Cracking

Shoulder Joint Offset
Patterns

Y-cracking

Clustering

Approximate spacing
at ______end
at middle
at ______end

Straight/Diagonal?

Distresses

Spalling

Punchouts

Repairs

Terminal and Construction Joints

General Notes

Photos: Roll # ________

Frame	Description	Frame	Description

Data collection sheet Type 1

Project Number:		Date:		Time:	
Direction:					
Location:					
Terminal Joints					
Longitudinal Cracks	Length				
	Spalling				
Transverse Cracks	Spacing				
	Width				
	Spalling				
Patterns	Clustering				
	Y-cracks				
	D-cracks				
Scaling					
Polish					
Popout					
Blowups					
TJC					
Punchout					
Repairs (PCC)					
Patch (AC)					
Patch Deterioration					
Bleeding and Pumping					
Longitudinal Joint Spalling					
Longitudinal Joint seal damage					

General Notes

Photos:	Roll #		
Frame	Description	Frame	Description

Data collection sheet Type 2

APPENDIX C

Appendix C Pavement Cross-Section Information

TYPICAL PAVEMENT SECTION

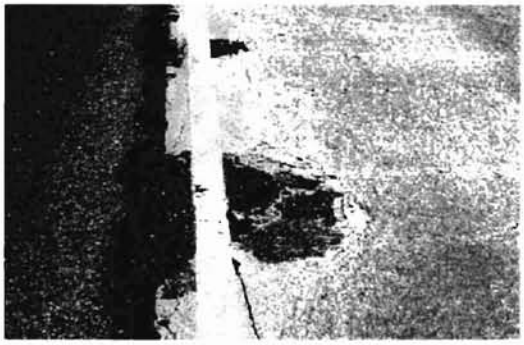
PROJECT INFORMATION					PAVEMENT FOUNDATION				SURFACE COURSE			
County	Highway	Project #	Control #	Year	Subgrade	Subbase Layer 2	Subbase Layer 1	Edge Drain	Shoulder	Thickness	% Long. Steel	% Trans. Steel
Division 1												
Cherokee	US 62	STP-11B(334)	62-11-02	1996			100 -mm OGPC	Yes	PCC	225	0.61	0.08
Muskogee	US 62	STP-51B(360)	62-51-06	1996	150 -mm Fly Ash	450 -mm Select Barrow	100 -mm OGPC	Yes	PCC	225	0.61	0.08
Muskogee	SH 165	MAFEGC-410(35)	165-51-53	1987	Method B	175 -mm Select	100 -mm Type A AC	No	PCC	225	0.50	0.08
Muskogee	US 69/64	SAP-51(392)	69-51-56 /44	1996		300 -mm Aggregate	100 -mm OG	Yes	PCC	250	0.61	0.07
Muskogee	US62	STP-404(66)	62-51-06	1993		450 -mm Select	100 -mm OGPC	Yes	PCC	225	0.61	0.08
Muskogee	US 69	MABRF-593(241)	69-51-18	1990	600 -mm Select		50 -mm Type B AC	No	PCC	250	0.51	0.11
Muskogee	I-40	I-40-6(86)	40-51-15	1973	150 -mm Lime Treated /Method B		100 -mm FABB	No	AC	200	0.61	0.00
Okmulgee	US 62/75	MABRF-53(141)	75-56-04	1991		300 -mm Select	75 -mm Type B AC	No	PCC	225	0.50	0.08
Sequoyah	I-40	IM-40-6(221)	40-68-23	1997	200 -mm Lime Treated		100 -mm Open Graded	Yes		250	0.00	0.00
Sequoyah	I-40	IR-40-6(220)	40-68-22	1991	Method B	300 -mm Select	100 -mm OGPC	No	PCC	250	0.61	0.07
Sequoyah	I-40	IR-40-6(222)	40-68-22	1989	150 -mm Select	150 -mm Type B Stabilized 0	100 -mm Econocrete	Yes	PCC	250	0.51	0.11
Division 2												
Atoka	US 69	F-299(99)	69-03-04	1990		300 -mm Aggregate	75 -mm Type A AC	No	PCC	250	0.61	0.07
Atoka	US 69	F-299(45)	69-03-04	1988			75 -mm Type C AC	No	PCC	225	0.50	0.08
Atoka	US 69	F-299(35)	69-03-04	1988		Varies	75 -mm Type C AC	No	PCC	225	0.50	0.08
Bryan	US 69/75	F-219(35)	69-07-03	1985	Method B	150 -mm Select	150 -mm Soil AC	No	PCC	225	0.50	0.08
Pittsburg	US 69	DPIY-204(001)	69-61-04	1994	Method B	300 -mm Aggregate	100 -mm OGPC	Yes	PCC	250	0.61	0.07
Pittsburg	US 69	MAF-186(185)	69-61-04	1991		300 -mm Stabilized Aggregate	100 -mm OGPC	Yes	PCC	250	0.61	0.07
Pittsburg	US 69	F-186(183)	69-61-03/04	1991	Method B	300 -mm Stabilized Aggregate	100 -mm OGPC	Yes	PCC	250	0.61	0.07
Pittsburg	US 69	MAF-186(180)	69-61-04	1993	Method B	300 -mm Aggregate	100 -mm OGPC	Yes	PCC	250	0.61	0.07
Division 3												
Okfuskee	I-40	IR-40-5(169)	40-54-22	1986	Method B		100 -mm CABB	No	PCC	225	0.50	0.08
Pontotoc	SH 3W	MAF-235(009)	03W-62-12	1990	Method B		100 -mm Type A AC	No	PCC	250	0.61	0.07
Division 4												
Logan	I-35	IR-35-4(115)	35-42-30	1989	Method B		75 -mm Type A AC	No	PCC	250	0.51	0.11
Noble	I-35	MAIR-35-4(111)	35-52-33	1990	Method B		100 -mm Econocrete	Yes	PCC	250	0.61	0.11
Oklahoma	SH 74	MAF-385(054)	74-55-63	1992		300 -mm Type B Aggregate	100 -mm OG	Yes	PCC	250	0.61	0.07
Oklahoma	SH 74	F-385(055)	74-55-63	1992		300 -mm Type B Aggregate	100 -mm OG	Yes	PCC	250	0.61	0.07
Oklahoma	SH 74	F-385(043)	74-55-63	1992		300 -mm Type B Aggregate	100 -mm OGBB	Yes	PCC	250	0.61	0.07
Oklahoma	I-35	I-IR-35-3(110)	35-55-15	1993		300 -mm Type B Aggregate	100 -mm OGBB	Yes	CRCP	250	0.61	0.07
Oklahoma	I-35	IR-35-3(049)	35-55-15	1994		300 -mm Type B Aggregate	100 -mm OG	Yes	CRCP	250	0.61	0.07
Oklahoma	I-40	IM-40-5(184)	40-55-68	1995	300 -mm Aggregate		100 -mm OG	No		250	0.00	0.00
Oklahoma	I-35	IM-NHIY-35-3(219)	35-55-15	1995		300 -mm Type B Aggregate 0	100 -mm OG	Yes	CRCP	250	0.61	0.07
Division 5												
Beckham	I-40	IM-40-2(119)	40-05-04	1993	Method B	100 -mm Aggregate 0	100 -mm OGPC	Yes	PCC	250	0.61	0.07
Division 6												
Cimarron	US 56/287/64	MAF-350(11)	56-13-02	1996		300 -mm Select	100 -mm OGPC	Yes	CRCP	250	0.61	0.07
Texas	US 54	NH-8N(001)	54-70-04	1997	200 -mm Fly Ash Modified		100 -mm AC Type A	No		250	0.00	0.00

County	Highway	Project #	Control #	Year	Subgrade	Subbase Layer 2	Subbase Layer 1	Edge Drain	Shoulder	Thickness	% Long. Steel	% Trans. Steel
Division 7												
Carter	I-35	I-35-1(48)	35-10-36	1970	Method B		100 -mm FABB	No	AC	200	0.61	0.08
Carter	I-35	I-35-1(53)	35-10-36	1971	150 -mm Lime Treated		100 -mm FABB	No	AC	200	0.61	0.08
Comanche	Rogers Lane	MAM-7780(002)		1992	150 -mm Lime Treated		150 -mm Type B AC	No	Curb	225	0.61	0.08
Murray	I-35	I-35-2(64)	35-50-32	1971	Method 2		100 -mm FABB	No	AC	200	0.61	0.08
Division 8												
Mayes	SH 20	DSB-49B(290)	20-49-06	1997	200 -mm Lime Treated	Select	100 -mm Open Graded	Yes		225	0.00	0.00
Mayes	US 412	F-398(35)	412A-49-46	1991		500 -mm Select	100 -mm Type A AC	Yes	PCC	250	0.61	0.07
Mayes	US 412	F-194(45)	412-49-18	1987	Select		87 -mm Type A AC	No	PCC	225	0.50	0.08
Mayes	SH 20	DPI-204(16)	20-49-06	1996			100 -mm OG	Yes		225	0.00	0.00
Mayes	US 69	F-593(252)	69-49-02	1991		600 -mm Select	75 -mm Type A AC	Yes	PCC	250	0.61	0.11
Rogers	US 412	MAF-194(35)	412-66-18	1986			Select Select	No	PCC	225	0.50	0.08
Rogers	US 169	STP-66B(306)	169-66-06	1995	200 -mm Lime Treated	150 -mm Aggregate	100 -mm OG	Yes	PCC	250	0.61	0.07
Tulsa	US 75	F-15(218)	75-72-93	1990		300 -mm Select	100 -mm Type A AC	No	CRCP	225	0.61	0.08
Tulsa	SH 33	IM-NHI-44-2(337)	42-72-78	1997		200 -mm Stabilized	Exist. Asphalt or Concrete	Yes		250	0.00	0.00
Tulsa	US 169	NH-30N(001)	169-72-81	1997	200 -mm Lime Treated		150 -mm Aggregate	Yes		250	0.00	0.00
Tulsa	I-244	I-244-2(101)	244-72-09	1973			125 -mm FABB	No	AC	200	0.61	0.08
Tulsa	US 169	MAF-521(075)	169-72-83	1990			100 -mm Type A AC	No	PCC	225	0.61	0.08
Tulsa	I-44	IR-44-2(328)	44-72-08	1991	Method B	600 -mm Select	100 -mm OCPC	Yes	PCC	300	0.60	0.06
Tulsa	I-44	ACIR-44-2(326)	44-72-78	1994		200 -mm Stabilized	250 -mm AC	No	CRCP	250	0.61	0.07
Tulsa	SH 67	RS-7248(100)	67-72-74	1994		300 -mm Select	100 -mm OG	Yes	PCC	250	0.61	0.07
Tulsa	SH 67	STPY-72C(404)	67-72-74	1994		300 -mm Select	100 -mm OG	Yes	PCC	250	0.61	0.07
Tulsa	I-244	I-244-2(108)	244-72-09	1974	150 -mm Lime Treated		125 -mm FABB	No	AC	200	0.61	0.08
Washington	US 75	F-15(213)	75-74-21	1990		Varies	AC AC	Yes	PCC	250	0.61	0.07
Washington	US 75	MAF-15(209)	75-74-21	1989		200 PCC (NB Only)	50 -mm Type B AC	No	PCC	225	0.50	0.08
Washington	US 75	NH-14N(13)	75-74-08	1996	200 -mm Lime Treated		100 -mm Open Graded	Yes		250	0.00	0.00
Washington	US 75	MAF-15(211)	75-74-21	1990		Varies	AC	Yes	PCC	250	0.51	0.11
Washington	US 75	NH-481(69)	75-74-08	1997	200 -mm Lime Treated		Varies	No	PCC	250	0.61	0.07

OGBB =	open graded bituminous base	Method B =	densify and optimize moisture in top
OGPC =	open graded portland cement		of subgrade
CABB =	coarse aggregate bituminous base		
FABB =	fine aggregate bituminous base	Econocrete =	portland cement concrete with reduced
AC A =	asphalt concrete Type A		cement content
AC B =	asphalt concrete Type B		
AC C =	asphalt concrete Type C	Soil Asph =	well graded soil (with asphalt cement to
AC A =	asphalt concrete Type A		produce mix of adequate strength.
SAB =	aggregate base		

APPENDIX D

APPENDIX D Full-Depth Repair: Pictorial Sequence



1. Punchout of repair. Typical around this location

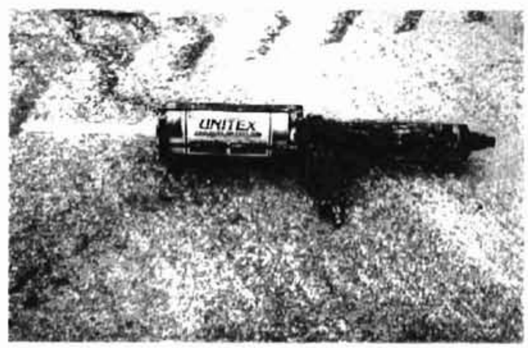
2. Full-depth sawed pavement for removal.

3. Removal of sawed sections.

4. 450 mm (18") longitudinal reinforcement exposed.

5. Drilling holes for transverse steel

6. Blowing out dust from holes.



7. Glue gun for epoxy binder.

8. Two cylinders containing epoxy compounds.

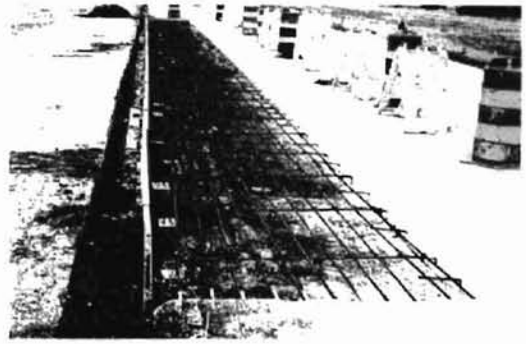
Figure D1. Full-depth repair

9. Injecting epoxy into holes.

10. Tapping transverse steel into epoxy-injected holes.

11. Close view of transverse steel installed.

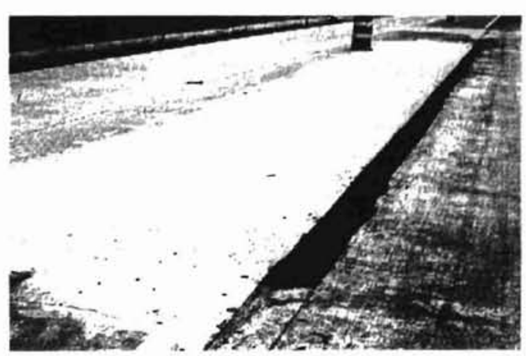
12. Longitudinal and transverse steel ready for connection.



13. All steel installed and ready for concreting.

14. Internal vibrator and levelling roller to consolidate and level concrete.

15. Curing concrete.



16. Repair completed.

Figure D2. Full-depth repair (cont.)

2

VITA

Joseph M. Wellington

Candidate for the Degree of

Master of Science

Thesis: ASSESSMENT OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT DESIGN AND BEHAVIIOR IN OKLAHOMA

Major Field: Civil Engineering

Biographical

Personal Data: Born in Accra, Ghana, On February 13, 1954, the youngest son of Hanun A. and Florence M. Wellington.

Education: Graduated from West Africa Secondary School, Accra, Ghana in June 1972, and from Mfantsipim Secondary School in June 1974; received Bachelor of Science degree in Civil Engineering from University of Science and Technology, Kumasi, Ghana in May 1979. Completed the requirements for the Master of Science degree with a major in Civil Engineering at Oklahoma State University in May, 1999.

Experience: Raised in Accra, Ghana; after graduation from college, employed by Asafo-Boakye and Partners, Accra, Ghana; employed by Molad and Molad Associates, Lagos, Nigeria; Miller and Long Construction, Bethesda, Maryland; Brown and Maclin Consultants, Oklahoma City, Oklahoma; Wyatt-Doyle and Butler Engineers, Oklahoma City, Oklahoma; Oklahoma Department of Transportation, Oklahoma City, 1998 to present.

Professional Memberships: Ghana Institution of Engineers, American Society of Civil Engineers, Oklahoma Society of Professional Engineers, American Concrete Society.