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THE EFFECTIVENESS OF THE FLY-ASH SLURRY INJECTION METHOD TO ELIMINATE DEPRESSED TRANSVERSE CRACKS

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January 2009

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16 Abstract

One of the primary causes of increasing roughness in asphalt pavements in Kansas has been naturally occurring transverse cracks. Maintenance forces continually tried to seal the cracks; however, the cracks continued to grow wider and the depressions deeper. A review of the History of Transverse Cracking on I-70 in the western half of Kansas reveals that very wide cracks (top down) developed in cold weather and no suitable treatments were available from 1960's through 1980's. It was common to have cracks about 60 feet apart, 4 to 5 inches wide, depressed 2 to 3 inches and extended across all lanes.

In this study, the nature and extent of transverse cracking in asphalt pavements on I-70 in Kansas was determined. A pavement investigation was conducted to determine the effectiveness of the Fly Ash Slurry Injection (FASI) method (a crack stabilization procedure) to eliminate or minimize the depression (bump) caused by the depressed pavement on both sides of the transverse cracks. The intent of the FASI was to fill the subsurface voids at severely distressed transverse cracks to delay depression and reflective cracking, because the pavements were structurally sufficient for the traffic loading. The initial objective of the study was to find a low-cost "maintenance," approach to improve ride by filling the transverse cracks and their associated depression. A variety of products and application procedures were attempted, with variable results. Most attempts re-cracked within a year, and depression soon followed.

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ABSTRACT

Because nearly 75% of the Kansas highway system is constructed of asphalt pavement, and the transverse cracks occur at intervals of about 50 feet, attempting to reduce or eliminate the effect of the crack and the depression is a sizable endeavor. The development of an effective method of filling the cracks and depressions would greatly improve the ride and safety for the motorist using the Kansas system of highways.

One of the primary causes of increasing roughness in asphalt pavements in Kansas has been naturally occurring transverse cracks. Maintenance forces continually tried to seal the cracks; however, the cracks continued to grow wider and the depressions deeper. A review of the History of Transverse Cracking on I-70 in the western half of Kansas reveals that very wide cracks (top down) developed in cold weather and no suitable treatments were available from the 1960's through the 1980's. It was common to have cracks about 60 feet apart, 4 to 5 inches wide, depressed 2 to 3 inches and extended across all lanes.

In this study, the nature and extent of transverse cracking in asphalt pavements on I-70 in Kansas was determined. A pavement investigation was conducted to determine the effectiveness of the Fly Ash Slurry Injection (FASI) method (a crack stabilization procedure) to eliminate or minimize the depression (bump) caused by the depressed pavement on both sides of the transverse cracks. The intent of the FASI was to fill the subsurface voids at severely distressed transverse cracks to delay depression and reflective cracking, because the pavements were structurally sufficient for the traffic loading. The initial objective of the study was to find a low-cost "maintenance," approach

to improve ride by filling the transverse cracks and their associated depression. A variety of products and application procedures were attempted, with variable results. Most attempts re-cracked within a year, and depression soon followed.

Ten sections of test pavement were constructed using FASI to fill the voids under the existing pavement adjacent to the transverse cracks, followed by cold milling, cold in-place recycling of the next 4 in., a hot recycle action, and a hot mix asphalt overlay. Pavement roughness values before and after the rehabilitation action were compared. Roughness values (right wheel path IRI [in./mi], westbound and eastbound) and transverse cracking trends (equivalent number of code 3 transverse cracks per 100 ft) were plotted for each year since 1988. The results indicated that a more extensive procedure, which involves using FASI, followed by milling and overlaying with hot mix asphalt, has provided several years of excellent service on these ten test sections of I-70 in western Kansas.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

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INTRODUCTION

One of the primary causes of increasing roughness in asphalt pavements in Kansas has been the naturally occurring transverse cracks. Asphalt pavement shrinks as it ages, and this causes tension forces great enough to result in transverse cracks. Once a crack is created, the moisture in the crack causes several problems: softens the subgrade, promotes bacterial growth resulting in further deterioration of the asphalt, high speed passage of the vehicle tire across the crack develops hydraulic pressures that abrade the wall of the crack and the high water pressure flushes the dislodged aggregate from the crack, allowing a depression to develop at each crack (Snethen and Ahmed 1991).

The depressed area usually associated with the crack causes a rough ride and vehicle wear, and the impact load from heavy vehicles causes accelerated deterioration of the pavement structure. Since about 75% of the system is asphalt pavement and the transverse cracks shown in Figure 1 occur at intervals of about 50 ft., attempting to reduce or eliminate the effect of cracking and depression is a sizable endeavor.

Transverse cracking of asphalt pavements is a problem across the state of Kansas with the severity of the problem varying from district to district based on such factors as pavement age, pavement cross section, traffic, asphalt properties, and maintenance procedures. The development of an effective method of filling the cracks and depressions would greatly improve the ride and safety for the motorist using the Kansas system of highways. It also would extend the life of the pavement by reducing the deterioration from water intrusion and from impact loading caused by vehicles bouncing as a result of the “bump,” as well as reducing future maintenance costs.

Figure 1: Transverse cracks on I-70

HISTORY OF TRANSVERSE CRACKS ON I-70 WEST OF SALINA

A review of the history of transverse cracking on I-70 in the western half of Kansas reveals that very wide cracks (top down, shown in Figure 2) developed in cold weather, and no suitable treatments were available from the 1960s through the 1980s. Maintenance forces continually tried to seal the cracks; however, the cracks continued to grow wider and the depression deeper. It was common to have cracks about 60 ft. apart 4 to 5 in. wide, depressed 2 to 3 in., and extended across all lanes and the shoulders. Pavements were all built during the 1960's utilizing primarily local materials (high % sand-gravel). After 27 years, it was estimated that over a mile of pavement had been "lost" on this 250 mile section of I-70 (Ramamurti and Jayaprakash 1987).

Figure 2: The nature of transverse cracking asphalt pavements on I-70

Transverse cracking of asphalt pavements is a costly pavement distress occurring in Kansas, which experiences prolonged periods of below freezing temperatures during the winter months. The cracks are caused by low-temperature-induced tensile stresses that exceed the tensile strength of the pavement material. Another factor that may have contributed to the initiation and growth of the transverse cracks was the use of locally available aggregate (sand and gravel) and locally produced asphalt that lacked low-temperature ductility. The majority of these cracks occur in the transverse direction, relative to the pavement and with regular frequency along the roadway shown in Figure 3.

Figure 3: Examination of transverse cracks

Once an open crack in asphalt has formed, the space tends to open further in cold periods and to close partially in warm periods (lateral movement primarily in response to thermal changes). Based on research, most crack movement occurs in a six- to eight-month period, with a peak opening about the end of February or early March. The causes of the growth of the cracks include environmental effects, aging, and type of mix. However, the magnitude of the crack opening is not a function of the distance between adjacent cracks (Bukowski 1990). Wide cracks developed in cold weather and gradually got wider with time in severe cold climate.

A review of the literature shows that water is needed for bacteria to grow and deteriorate the asphalt (Ramamurti, Jayaprakash, and Crumpton 1984). Soft, loosely bound, asphalt concrete is often present between the rubble and sound materials. This seems to indicate a cause and effect relationship between bacteria and asphalt deterioration, since the rubble and loosely bound material (rubble-like deteriorated material) contained bacteria. The soil is the main habitat for bacteria. The bottom of the pavement tends to stay moist longer than would the exposed soil without the asphalt road above it. The soil-asphalt interface provides a great environment for bacterial existence. A crack in the asphalt allows air and water to contact the crack interface and provides more surface area of asphalt available to the bacteria. Therefore, full depth hot mix recycling would be more effective than partial depth recycling in retarding bacterial decay at cracks and would likely destroy bacteria that are already in the pavement shown in figures 4 through 6 (Ramamurti and Jayaprakash 1987). However, the cost would be very high (Fager 2004).

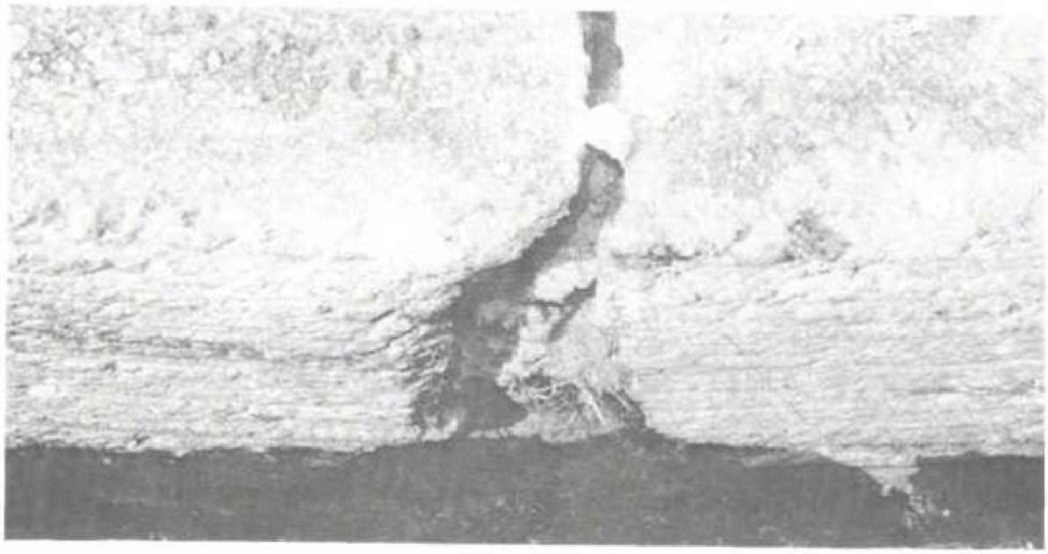


Figure 4: Photograph of vertical profile of crack. Inverted trough shaped deterioration is in the center of the bottom half of the photograph. The transverse crack at the pavement surface shows in upper center of photograph (Ramamurti and Jayaprakash 1987).

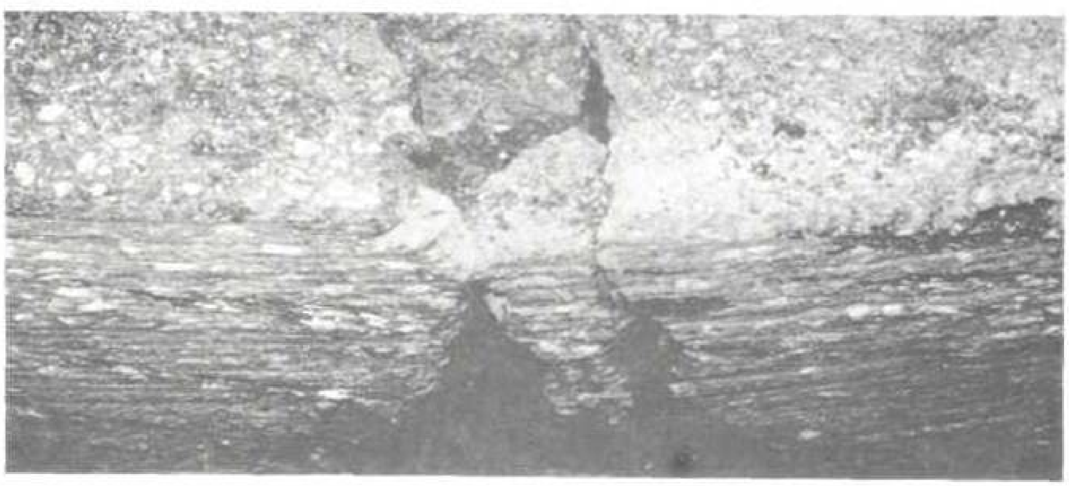


Figure 5: Photograph of vertical profile of a crack. Note the transverse crack width at the pavement surface in the center of the upper half of the photograph. The crack flares out downward. Loosely held rubble like material in the center of the deteriorated area (Ramamurti and Jayaprakash 1987).

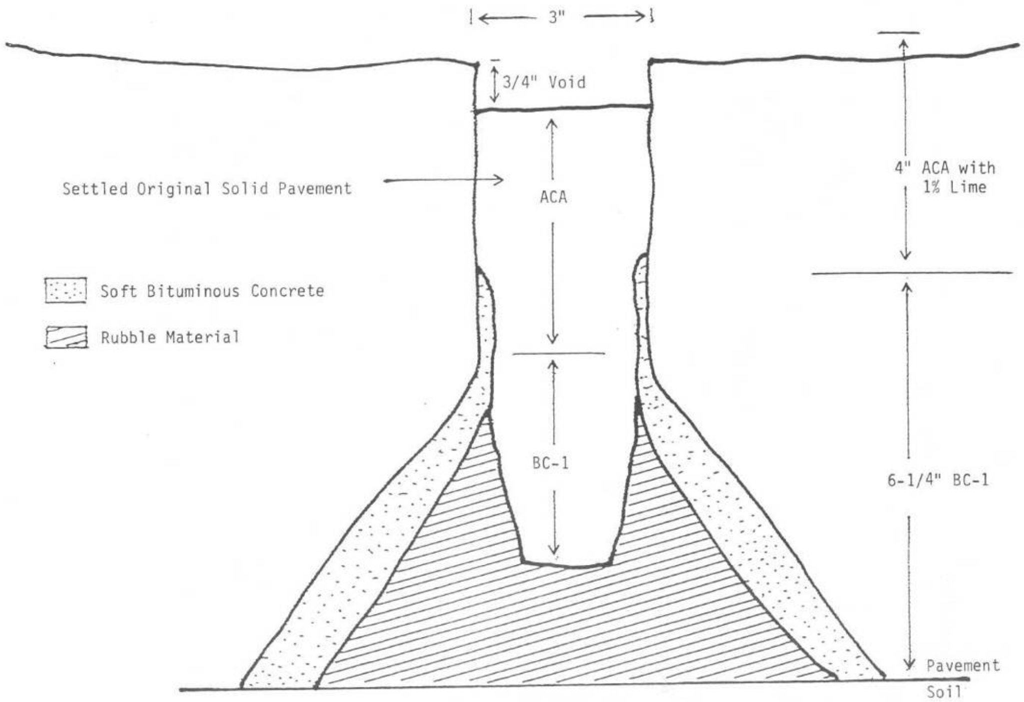


Figure 6: Vertical profile at a transverse crack in bituminous pavement. The inverted trough shaped deterioration is mostly within BC-1 with no added lime (Ramamurti and Jayaprakash 1987).

A research study, (Parcells, 2004), “Taking the Bang out of Transverse Cracks: Fly-ash Slurry Injection Method,” began in FY 1991 as part of the annual Highway Planning and Research Work Program. The initial objective of the study was to evaluate a low-cost “maintenance” approach that had been used previously to fill transverse cracks and the associated depression. A variety of products and application procedures were used to fill transverse cracks and the associated depressed area in highways that did not need structural rehabilitation. Most attempts had re-cracked within a year, and further deterioration soon followed.

In the present study, the major objectives of the research included the following: (1) determine the nature and extent of transverse cracking asphalt pavements on I-70 in

Kansas and (2) determine the effects of the fly ash slurry injection (FASI) maintenance action (a crack stabilization procedure) to eliminate or at least reduce the bump caused by the transverse crack and the depression on asphalt pavements. The intent of the FASI action was to fill the voids at severely distressed transverse cracks and to stabilize the soil and rubble material below the crack, thus delaying reflective cracking.

OTHER REPAIR TECHNIQUES OF TRANSVERSE CRACKS IN ASPHALT PAVEMENTS

Traditional maintenance treatments during the 1980's such as crack sealing, slurry crack filling, maintenance patching, milling, overlays, etc. were not effective for very long.

Pavement surface maintenance represents a significant portion of highway maintenance activities. Pavement cracking is one of the most troublesome aspects of surface pavement condition and the predominant indicator of approaching failure. Highway managers, engineers, and researchers disagree on the methods and effectiveness of crack repair.

The information presented in this section was collected over the years from brief reports produced as each technique was tested and evaluated in order to determine the most cost effective way to eliminate or at least reduce the "bump" caused by the transverse crack and the depression on asphalt pavements. A wide variety of repair techniques were attempted, but most resulted in only brief improvement in the ride. The cracks and depressions soon returned causing poor ride quality, reduction of pavement life, and increased maintenance costs.

As the milling technology developed, that technique was applied in an effort to remove the depression prior to placing the overlay. The deterioration of the asphalt below the surface was bad enough in some areas that it was decided to remove and replace the asphalt full depth for 1 to 2 feet each side of the crack. This repair was time consuming, expensive, and frequently resulted in two cracks.

KDOT practices for dealing with transverse cracking of asphalt pavements were reviewed. Consideration was given to the cost of materials, labor and time to install, and how long the repair lasts. Although detailed field evaluations were not conducted for most of the field trials of the various preventative maintenance or remedial repair procedures used by the District offices, the observations made and experience gained indicated that some procedures performed better than others. Some remedial repair methods that have not worked well include:

1. The Use of Fog sealing:

Fog sealing was used as a preventative maintenance procedure to reduce and/or delay the extent and severity of transverse cracking. In the three Districts where fog sealing was routinely used (i.e., annually or semi-annually) on pavements starting 3 to 4 years after construction, the reported incidence of transverse cracking was significantly less. The key to a successful fog sealing program is to start as soon as hairline cracks appear in the roadway surface and to continue the process periodically as long as the transverse cracks are no more than ¼ to ½ in. wide. Once the cracks reach ¼ to ½ in. wide or more, crack sealing should be started and continued on an as-needed basis.

2. The Use of Heater Scarification with Overlay:

Another less expensive technique included heater scarification (also referred to as surface recycling) with overlay. The heater scarification with overlay was not very satisfactory because the depth of penetration was not sufficient to handle the depression, and the axis of the roller drum was parallel to the crack and thus tended to recreate the depression.

3. The Use of Latex Modified Slurry Seal:

The latex modified slurry seal does not require rolling but the technique is designed to move continuously along the highway and not stop every 60 feet to fill a crack. The technique was modified by pre-filling the crack and depression by dumping a puddle of material at each crack and strike it off with a straight edge about 4 feet long. Many of the depressions were wider than 4 feet and thus were not filled completely. The procedure was very slow and thus expensive. Unless a second pass was made covering the full lane width, the result was a patch every 60 feet which did not look or feel smooth. This technique only gave short term relief.

4. The Use of Geo-textile Fabrics:

Additional techniques which included the use of geo-textile fabrics such as Petromat, Poly-Guard, Pave Prep, and Road Glas were tested at locations throughout the state in an effort to provide additional strength in tension and thus prevent, or at least reduce, the re-appearance of the transverse and longitudinal cracks. Methods of application included: 1) placing the fabric on the existing surface with a slurry or chip seal cover over the fabric; 2) milling a trench with the crack in the middle, placing the fabric in the trench and refilling with hot mix asphalt; 3) milling, placing fabric, refilling with hot mix and then overlaying with hot mix asphalt; and 4) placing the fabric on the existing surface and overlaying with hot mix asphalt. The performance of each type repair was monitored and compared to a similar repair without the fabric. No long term benefit was realized by using the fabric. Sites where a trench was milled usually produced two cracks instead of one.

5. The Use of a Fiberized Asphalt Crack Sealing Material:

A hot pour asphalt crack sealing material with cut poly-propylene fibers mixed in to reinforce the material, was placed as a crack filler plus a small amount on the surface as a band aid. Generally, the material remained pliable with good tensile strength. The band aid material in the wheel path had been pushed upstream against the direction of traffic as much as 6 inches due to thrust action of vehicle tires shown in Figure 7 and 8. The movement of the surface layer of the material seems excessive and results in the cracks becoming uncovered. However, it did not run out of the crack onto the shoulder. In the wheel path, the material had remained mashed in the crack and was effectively closing the crack. Between the wheel paths and outside the wheel path toward the centerline and toward the shoulder, the material did not effectively keep the crack sealed. The material had sunk down and was no longer bonded to the sides of the crack. Consequently, the transverse cracks had continued to grow and none were “sealed.” However, the longitudinal centerline crack was about the same as it had been when sealed. The material was still in place and the crack still fairly well sealed.

Figure 7: Some remedial repair methods did not work well.

Figure 8: The use of a fiberized asphalt crack sealing material

In June 1987, a Fiberized asphalt crack sealing material was placed on a test section on K-4 north of US-24 in Jefferson County, Kansas in the vicinity of MP 336.95 to 337.2 in the northbound lane. The material was provided and placed by Musselman and Hall Contractors, of Kansas City, Mo., as a no cost demonstration of the cut polypropylene fiber reinforced asphalt crack sealer. The mixture was heated in an oil bath pot and was pumped through a small hose and nozzle into the cracks and onto the surface to form a band about 6 inches wide. The transverse cracks ranged from ¼ inch to 1.5 inches wide and most had some sidewall depression. The centerline longitudinal crack was ¼ inch or less and no depression was noted. The volume of material used was enough to fill the crack which had not been cleared out. No attempt was made to fill the entire depressed area. On September 20, 1989, the performance of the crack sealer was evaluated after 27 months exposure to weather and traffic. Generally speaking, the product had failed as a crack sealer.

6. Mill, Fill, and Overlay

During the 1990 construction season, this portion of K-4 was included in a resurfacing and pavement widening project and thus, the test section was covered over. During this project, most of the transverse cracks were milled out to a depth of 4 inches making a trench 12” wide at the bottom with side wall slope of 1:1 resulting in a top opening of approximately 20 inches. The remaining crack in the bottom of the trench was sealed with a rubber asphalt sealer, and the trench was backfilled with hot mix asphalt. The roadway was widened three feet on each side with asphalt 4.5 inches deep, and the entire 12’ lane overlaid with 1.5 inches of BM-1B hot mix. While visiting the site in the spring of 1991, it was noted there are now two hairline transverse cracks about 20” apart at the locations where milling was done. Since no evidence of the fiber asphalt crack seal remained, that study was closed.

The cost of the each technique varies as widely as the amount of effort required to install the repair. However, none of the techniques was effective at eliminating or even reducing the crack growth or the growth of the associated depression for more than a few months.

ORIGINATION OF THE FLY ASH SLURRY INJECTION (FASI) METHOD

Asphaltic concrete overlays and other maintenance actions temporarily correct the riding surface. But as reflection cracks appear, the degradation continues, and the depression is again formed. A need, therefore, exists to identify a procedure which would retard or eliminate the cracking and degradation of the new overlay. The rationale of McReynolds and Parcells for recommending the use of fly ash slurry injection as a new maintenance action on these pavements was threefold:

1. Fill the voids to help support the overlay.
2. Re-cement and strengthen the loose material.
3. Create an environment where asphalt consuming bacteria could not flourish.

They recommended using conventional PCC slab mud jacking equipment and procedures to inject the slurry. This method would have the added benefit of introducing a material that would retard bacterial growth, potentially stabilize the loose material at the bottom of the crack, and possibly create a “bulb” of material below the crack to help support it.

By 1985, most of the pavement on I-70 west of Salina, Kansas, to Colorado had been overlaid two or more times during its 15- to 25-year life and ranged from about 10 to 24 in. thick. Each overlay provided a new riding surface and filled most of the depressions and cracks. However, on some overlays, the crack would reappear within weeks and the depression would start to grow. Therefore, a review of existing KDOT policies and procedures for crack sealing and crack filling was conducted. First project was constructed during 1988, however, that project was not included in this report because of insufficient data.

FASI METHOD

(See Appendix A)

1. Inject fly ash slurry into the area below each crack/depression through holes drilled into the pavement on both sides of the crack.

2. Fill the voids under the existing pavement adjacent to the transverse cracks and fill the transverse crack but do not lift the pavement.

3. After the slurry cures, cold mill 4" and recycle existing pavement using cold in-place recycling action to level and rehabilitate the surface prior to placing a Hot Mix

Table 1: Projects selected for FASI study (I-70 in western Kansas)

Asphalt (HMA) overlay. Costly full-depth recycling is no longer necessary.

As noted in Table 1, ten sections of I-70 in 5 different counties and including over 111 miles of 4-lane divided highway were rehabilitated between 1996 and 2000 using the FASI method. Several other sections were also rehabilitated using the FASI method but the ten selected sections had more complete performance data.

The Pavement roughness values, using the International Roughness Index (IRI) before and after the rehabilitation action, are shown in figures 10 through 19. Roughness values were collected in the right wheel path of the driving lane both westbound and eastbound for each year from 1989 to 2005. Figures 10 through 19 demonstrate that a more extensive procedure, which involves using FASI, followed by milling and overlaying with hot mix asphalt, has provided several years of excellent service on the ten sections of test pavement of I-70 in western Kansas. As a result, FASI was identified as an effective crack repair procedure that can extend pavement service life and reduce future maintenance costs.

Examination of transverse cracks at the ten field sites shown in tables 4 through 13 confirm that, in most cases, transverse cracks originate at the pavement surface and extend down into or through the pavement. The primary cause of transverse cracking is thermal-induced stress that causes contraction of the asphalt concrete surface layer. A low average temperature has been found to have a significant effect on transverse cracking. The average spacing between the cracks decreases with a decreasing average temperature (Traxler 1966).

No.	Project no.	County	Completion date	Begin M. P.	End M. P.
1	K-5982-01	Ellsworth	2000	0	16.945
2	K-5983-01	Ellsworth	2000	16.945	23.248
3	[illegible]	[illegible]	[illegible]	[illegible]	19.254
4	[illegible]	[illegible]	[illegible]	[illegible]	37.508
5	K-5980-01	Lincoln	1998	0	7.247
6	K-2610-02	Saline	1997	8	14.9
7	K-5572-01	Thomas	1996	0	4.393
8	K-5908-01	Thomas	1998	4.393	10.342
9	M-1775-01	Thomas	1996	19.070	28.031
10	K-5979-01	Thomas	1998	28.062	39.554

Figure 9: Contraction of the asphalt concrete surface layer

Transverse crack depressions are caused by an ingression of water through the cracks in the pavement to the subgrade soils. This causes softening of the subgrade soil and subsequent depression adjacent to the crack. Additionally, pumping of fines from the base and subgrade through the cracks contributes to the loss of support. The plastic limit of the fine-grained soils has been correlated with crack indexes such as number of cracks per 1,000 ft. This indicates that pavements overlying fine-grained soils have a greater risk of transverse cracking (Hicks, Kimberly, and Moulthrop 1997).

The FASI technique seems to have been the most successful rehabilitation method. The injected fly ash slurry appears to have stabilized the deteriorated material in the vicinity of the crack and has resulted in the elimination of the depression for up to 12 years. This technique has been used in many locations across the state, resulting in improved highway smoothness. The ride from Goodland to Salina has been greatly improved, and the bang from the transverse cracking is gone.

Table 2: Pavement roughness values before and after the rehabilitation action

No.	Project no.	Completion date	Before rehabilitation	After rehabilitation	Improvement (%)
1	K-5982-01	2000	132	40	70
2	K-5983-01	2000	115	45	61

3	K-5978-01	1998	155	50	68
4	K-5981-01	1999	135	40	70
5	K-5980-01	1998	160	60	63
6	K-2610-02	1997	135	48	64
7	K-5572-01	1996	135	60	56
8	K-5908-01	1998	165	48	71
9	M-1775-01	1996	120	48	60
10	K-5979-01	1998	160	40	75

Furthermore, FASI has proven to be a cost effective maintenance action for pavements with depressed wide cracks shown in Table 3.

Table 3: Cost data on five projects selected for FASI (I-70 in western Kansas)

Project Number	Year	Project Length (miles)	FASI			CIR	
			Total Cost	Cost per hole	Cost per mile	Total cost	Cost per mile
70-32 K-5978-01	1998	19.254	$107,139	$7.29	$5,565	$496,193	$25,771
70-97 K-5908-01	1998	5.949	102,412	21.85	17,215	379,176	63,738
70-53 K-5980-01	1998	7.247	294,783	11.92	40,677	966,043	133,302
70-97 M-1775-01	1996	8.961	210,412	10.98	23,481	638,845	71,292
70-97 K-5979-01	1998	11.492	84,463	20.13	7,350	444,540	38,683
Average Cost			$159,842	$14.43	$18,858	$584,959	$66,557

Table 4: I-70 in Ellsworth County, CMP 0.000 to CMP 16.945

Year	Project No.	Completion Date	Activity
1984			
1985			
1986	M-1436-01	1986	Slurry Seal
1987			
1988			
1989			
1990			
1991			
1992	K-4664-01	1992	Slurry Seal +2.5” HR-SP
1993			
1994			
1995			
1996			
1997			
1998			
1999			
2000	K-5982-01	2000	1” SM-9.5T(PG64-28) +5.9” SR-19B(PG58-28) +4” CIR +FASI
2001			
2002			
2003			
2004			
2005			
2006	K-0384-01	In Progress	Novachip (Ultra-thin Bonded/ Type B/PG70-28)

Table 5: I-70 in Ellsworth County, CMP 16.945 to CMP 23.248

Year	Project No.	Completion Date	Activity
1984			
1985			
1986	M-1436-01	1986	Slurry Seal
1987			
1988			
1989			
1990			
1991			
1992	K-4664-01	1992	Slurry Seal +2.5” HR-SP
1993			
1994			
1995			
1996			
1997			
1998			
2009			
2000	K-5983-01	2000	1” SM-9.5T(PG64-28) +5.9” SR-19B(PG58-28) +4” CIR +FASI
2001			
2002			
2003			
2004			
2005			
2006	K-0384-01	In Progress	Novachip(Ultra-thin Bonded/ Type B/PG70-28)

Table 6: I-70 in Gove County, CMP 0.000 to CMP 19.254

Year	Project No.	Completion Date	Activity
1984			
1985	M-1382-01 *CMP 0.0~4.3*	1985	Milling
1986	K-4244-01 *CMP 0.0~18.0*	1986	Slurry Seal
1987			
1988			
1989			
1990			
1991			
1992			
1993			
1994			
1995			
1996			
1997			
1998	K-5978-01	1998	1” BM-1T(PG70-28) +5.5” HR-SP(AC-5) +3.9” CIR +FASI
1999			
2000			
2001			
2002			
2003			
2004			
2005	K-9328-01	2005	Novachip (Ultra-thin Bonded/ Type B/PG70-28)
2006			

Table 7: I-70 in Gove County, CMP 19.254 to CMP 37.508

Year	Project No.	Completion Date	Activity
1984			
1985	M-1366-01	1985	Milling
1986			
1987			
1988			
1989			
1990	K-3713-01	1990	2" HR-SP
1991			
1992			
1993			
1994			
1995	K-5562-01	1995	Milling
1996			
1997			
1998			
1999	K-5981-01	1999	1" BM-1T(PG70-28) +5.5" HR-2C(PG64-28) +4" CIR +FASI
2000			
2001			
2002			
2003			
2004			
2005	K-9447-01	2005	Conventional Seal
2006			

Table 8: I-70 in Lincoln County, CMP 0.000 to CMP 7.247

Year	Project No.	Completion Date	Activity
1984			
1985			
1986	M-1435-01	1986	Slurry Seal
1987			
1988			
1989			
1990			
1991			
1992	K-4663-01	1992	Slurry Seal +1.5" HR-SP
1993			
1994			
1995			
1996			
1997			
1998	K-5980-01	1998	1" BM-1T(PG70-28) +5.9" HR-2C(PG64-28) +3.9" CIR +FASI
1999			
2000			
2001			
2002			
2003			
2004			
2005	K-8887-01	In Progress	Novachip (Ultra-thin Boned/ Type B/PG70-28)
2006			

Table 9: I-70 in Saline County, CMP 8.000 to CMP 14.900

Year	Project No.	Completion Date	Activity
1984			
1985			
1986			
1987			
1988			
1989			
1990	K-3808-01 *CMP 9.8~14.9*	1990	1.5" BM-1 (Only Westbound Lanes)
1991			
1992			
1993			
1994			
1995			
1996			
1997	K-2610-02 *CMP 8.0~13.7*	1997	**Reconstruction:** 1" BM-1T(PG70-28) +6" HR-2C(AC-5 & AC-10) +4" Unbound Drainable Base with Geogrid and Edge Drains +6" Fly Ash Modified Bituminous Sub-base +FASI
	CMP 13.7~14.9	1997	**Reconstruction:** 1" BM-1T(PG70-28) +15" HR-2C(AC-5 & AC-10) +6" Fly Ash Modified Subgrade
1998			
1999			
2000			
2001			
2002			
2003			
2004	K-8435-01	2004	Conventional Seal
2005			
2006			

Table 10: I-70 in Thomas County, CMP 0.000 to CMP 4.393

Year	Project No.	Completion Date	Activity
1984			
1985	M-1379-01	1985	Milling
1986			
1987			
1988			
1989			
1990	K-3473-01	1990	3” HR-SP
1991			
1992			
1993			
1994			
1995			
1996	K-5572-01	1996	1.5” BM-1B +5” HR-2C(AC-10) +4” CIR +FASI
1997			
1998			
1999			
2000			
2001			
2002	K-8574-01	2002	Slurry Seal
2003			
2004			
2005	K-9449-01	In Progress	2” Overlay:SM-9.5T(PG76-28) and SM-12.5A(PG76-28)
2006			

Table 11: I-70 in Thomas County, CMP 4.393 to CMP 10.342

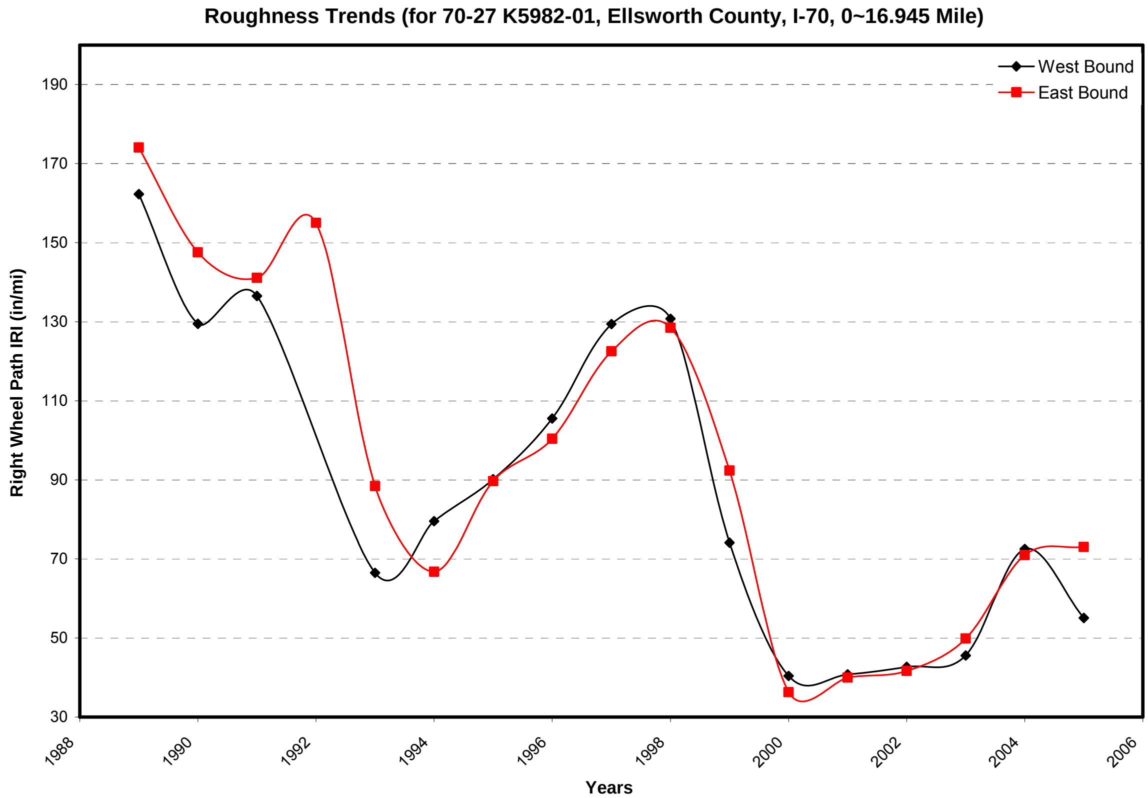
Year	Project No.	Completion Date	Activity
1984	M-1301-01	1984	Milling
1985			
1986			
1987			
1988			
1989			
1990	K-3473-01	1990	3" HR-SP
1991			
1992			
1993			
1994			
1995			
1996			
1997			
1998	K-5908-01	1998	1.5" BM-1T +5" HR-2C(AC-10) +4" CIR +FASI
1999			
2000			
2001			
2002	K-8574-01	2002	Slurry Seal
2003			
2004			
2005			
2006			

Table 12: I-70 in Thomas County, CMP 19.070 to CMP 28.031

Year	Project No.	Completion Date	Activity
1984			
1985	M-1380-01	1985	Milling
1986			
1987			
1988			
1989			
1990	K-3474-01	1990	2” HR-SP
1991			
1992			
1993			
1994			
1995	K-5288-01	1995	Conventional Seal
1996	M-1775-01	1996	1” BM-1T(AC-10) +5” HR-2C(AC-10) +4” CIR +FASI
1997			
1998			
1999			
2000			
2001			
2002			
2003			
2004			
2005	K-8886-01	2005	1” SM-9.5T(PG76-28) +2” SM-12.5A(PG76-28) +2” Cold Mill
2006			

Table 13: I-70 in Thomas County, CMP 28.062 to CMP 39.554

Year	Project No.	Completion Date	Activity
1984			
1985	M-1380-01	1985	Milling
1986			
1987			
1988			
1989			
1990	K-3474-01	1990	2" HR-SP
1991			
1992			
1993			
1994			
1995	K-5288-01	1995	Conventional Seal
1996			
1997			
1998	K-5979-01	1998	1.5" BM-1T(PG70-28) +5.5" HR-2C(AC-5) +3.9" CIR +FASI
1999			
2000			
2001			
2002			
2003			
2004	K-9444-01	2004	Conventional Seal
2005			
2006			



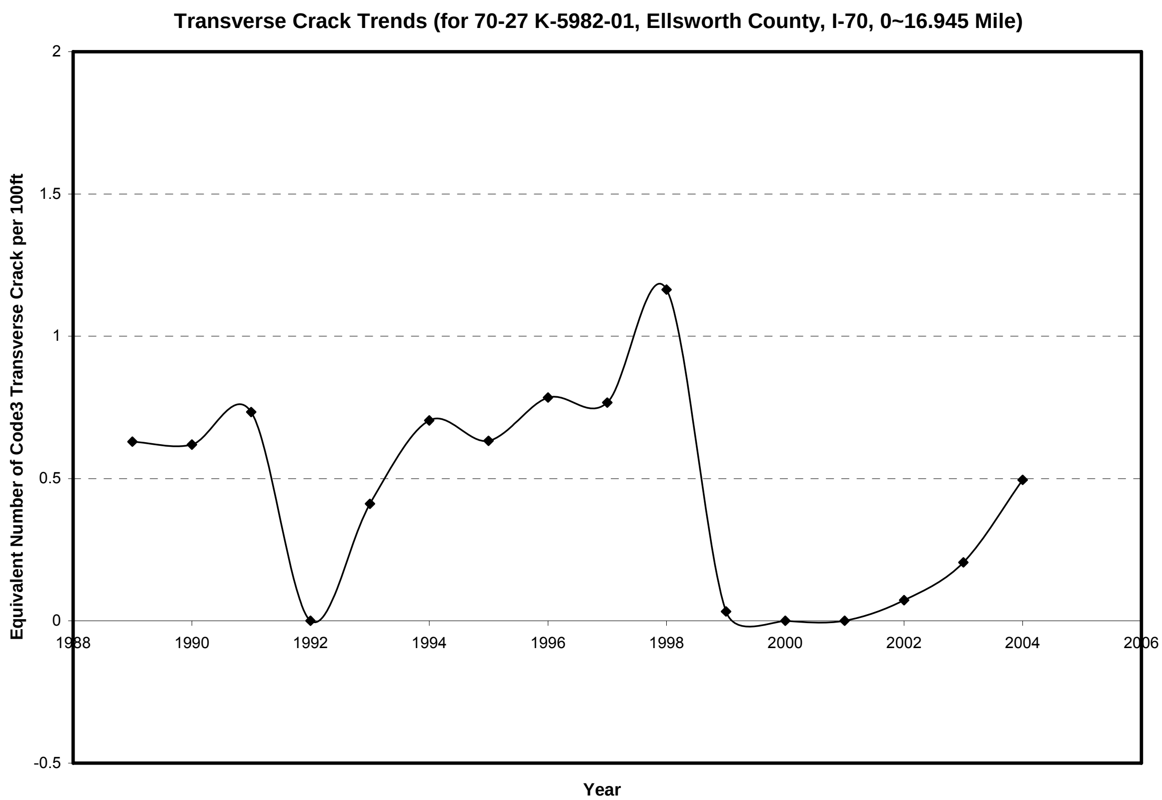
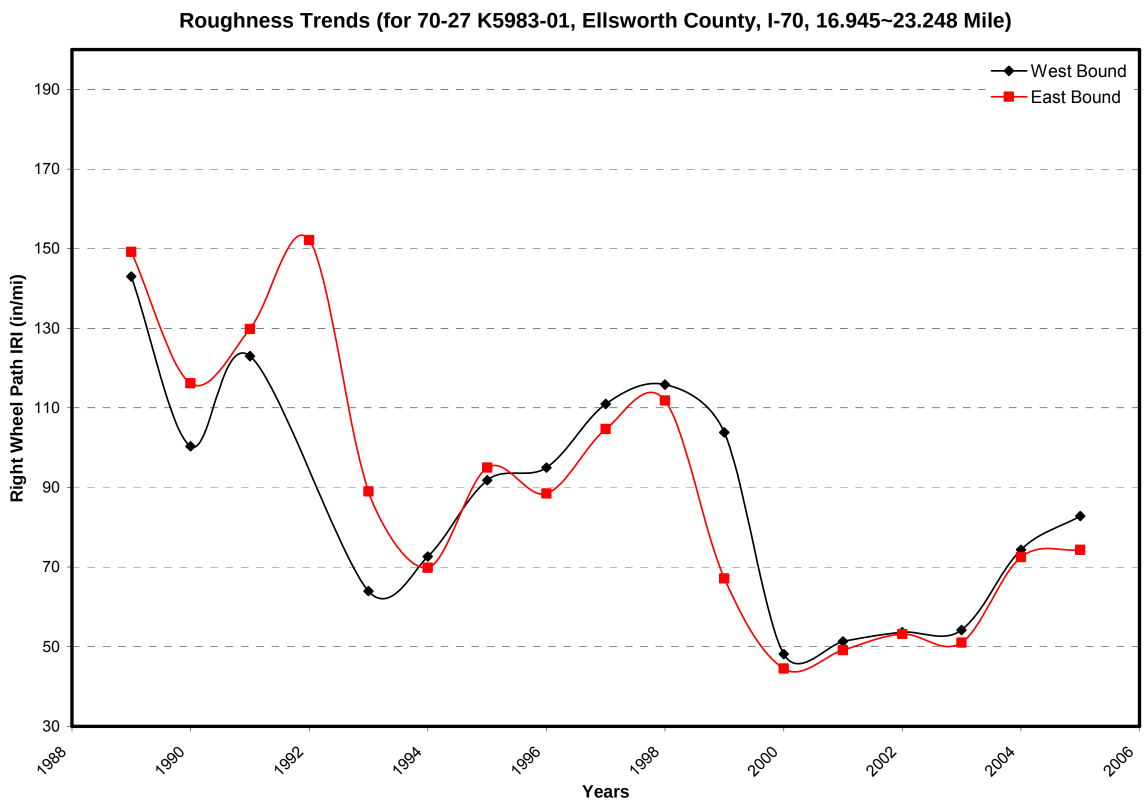


Figure 10: K-5982-01, completion date 2000 with a 70% improvement



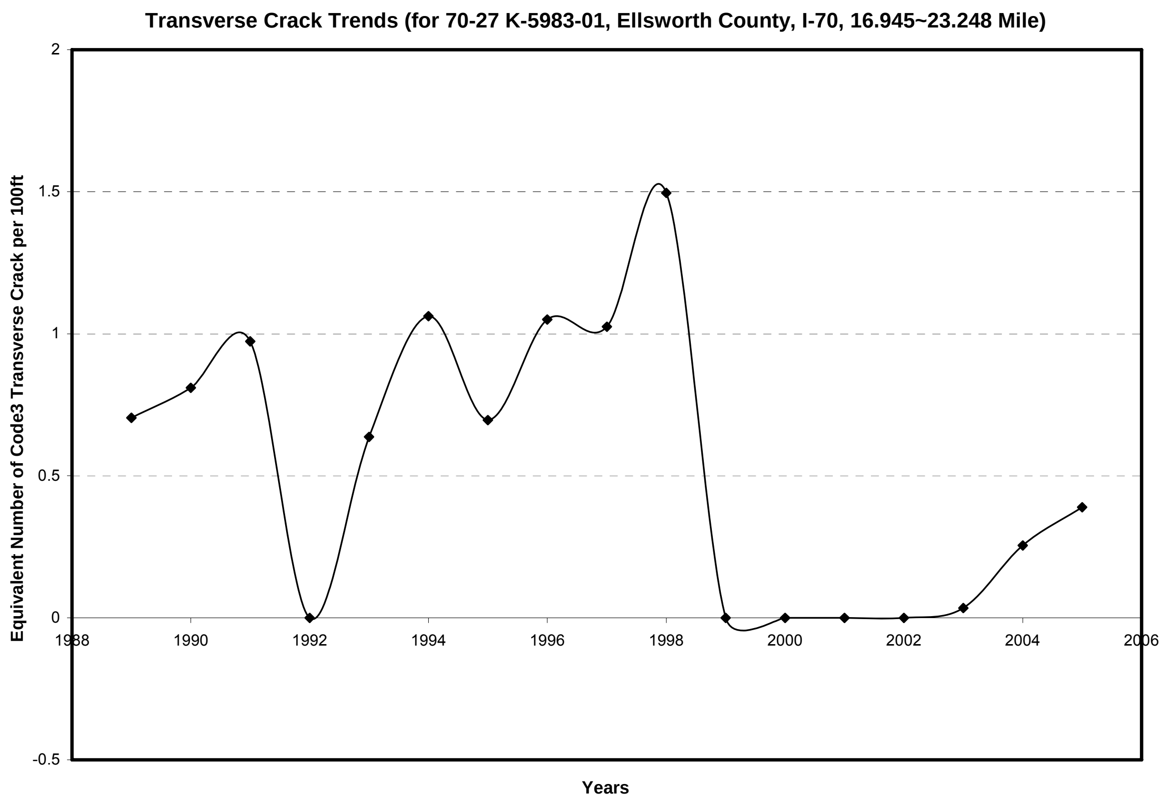


Figure 11: K-5983-01, completion date 2000 with a 61% improvement

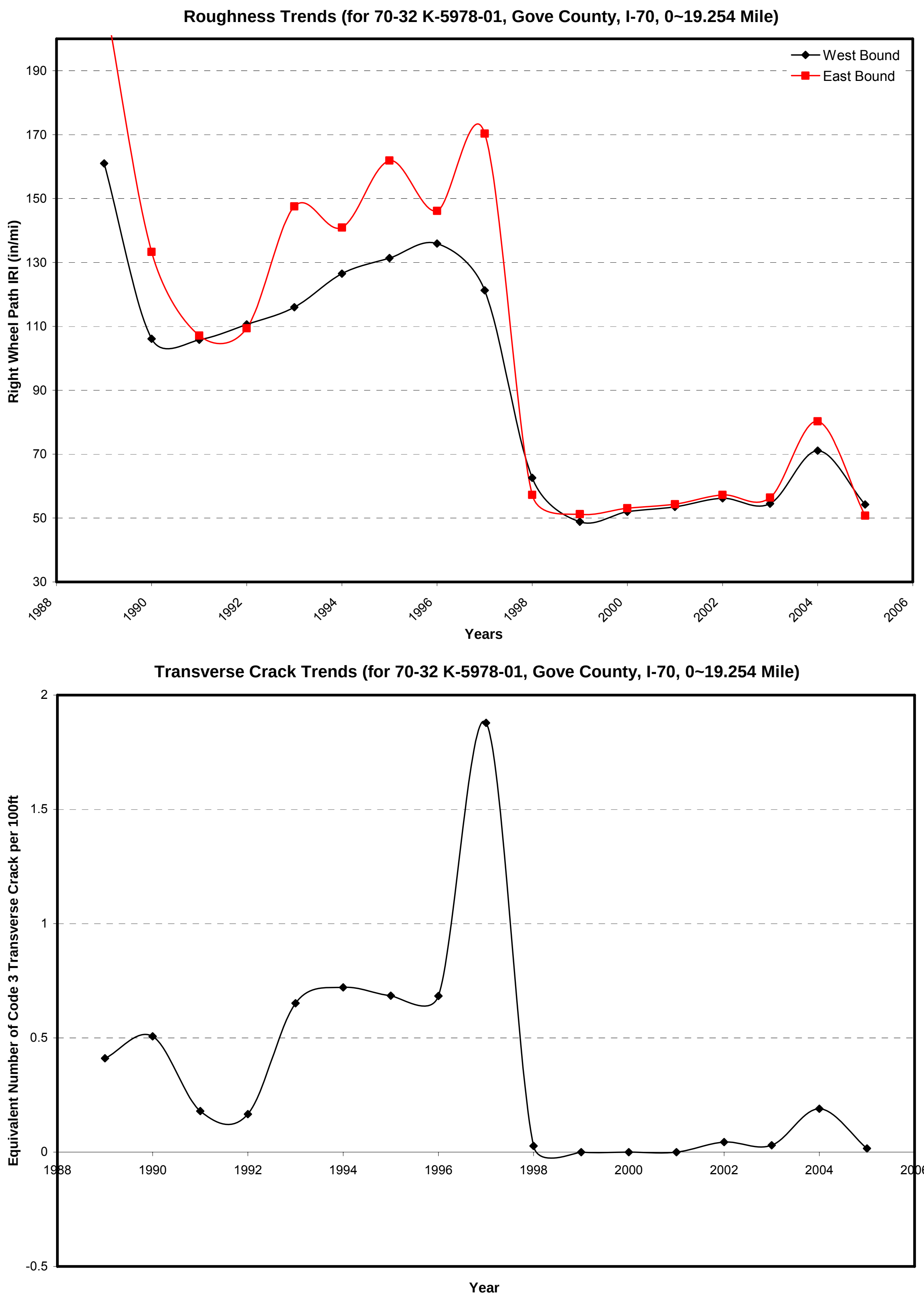
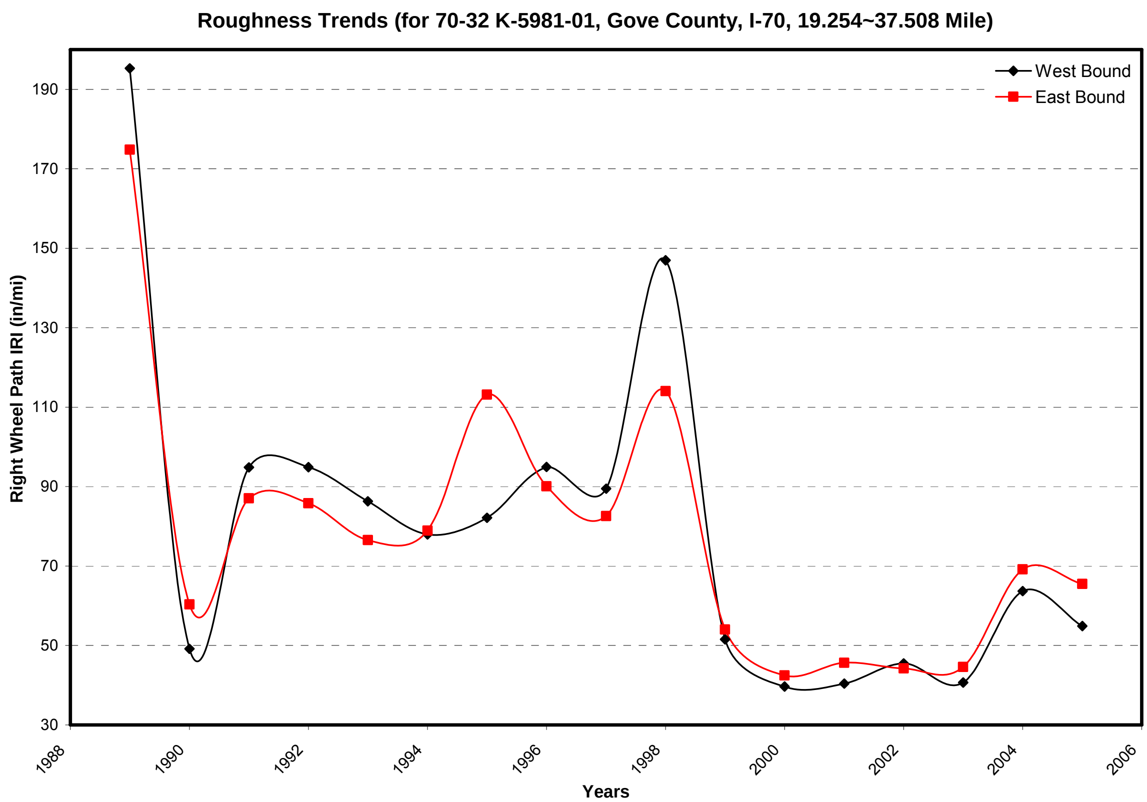


Figure 12: K-5978-01, completion date 1998 with a 68% improvement



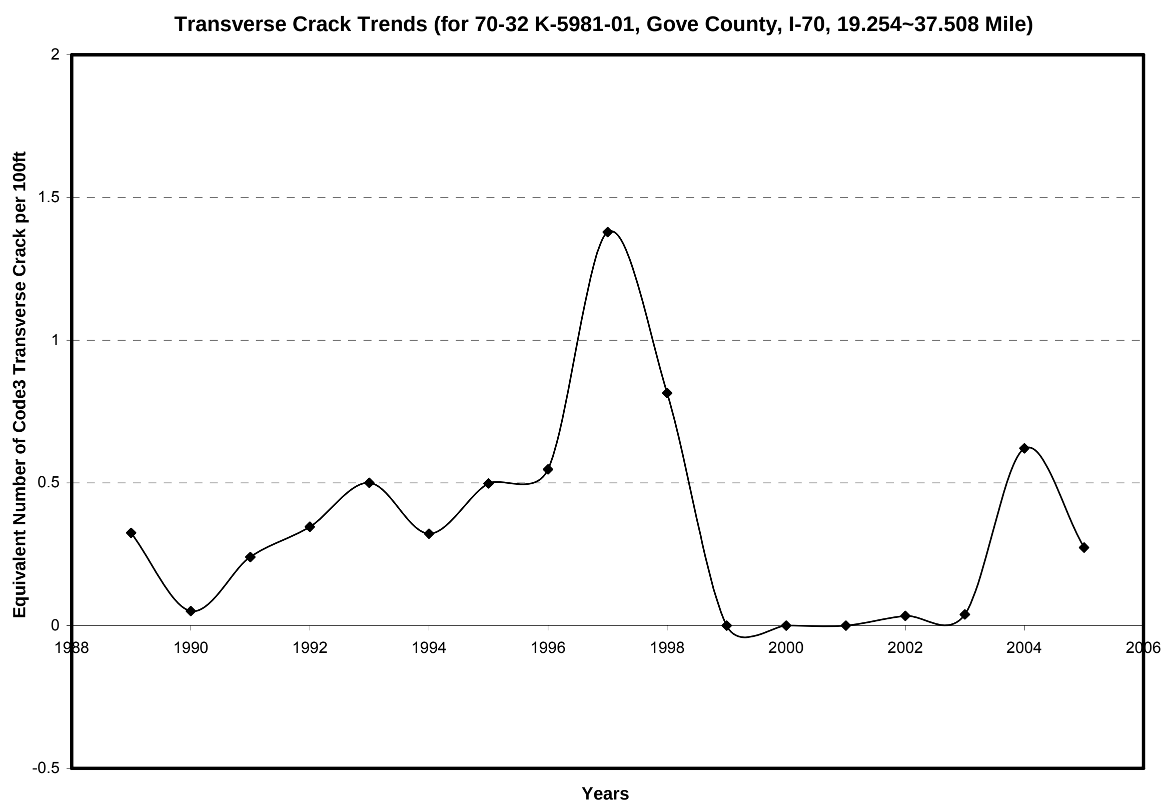
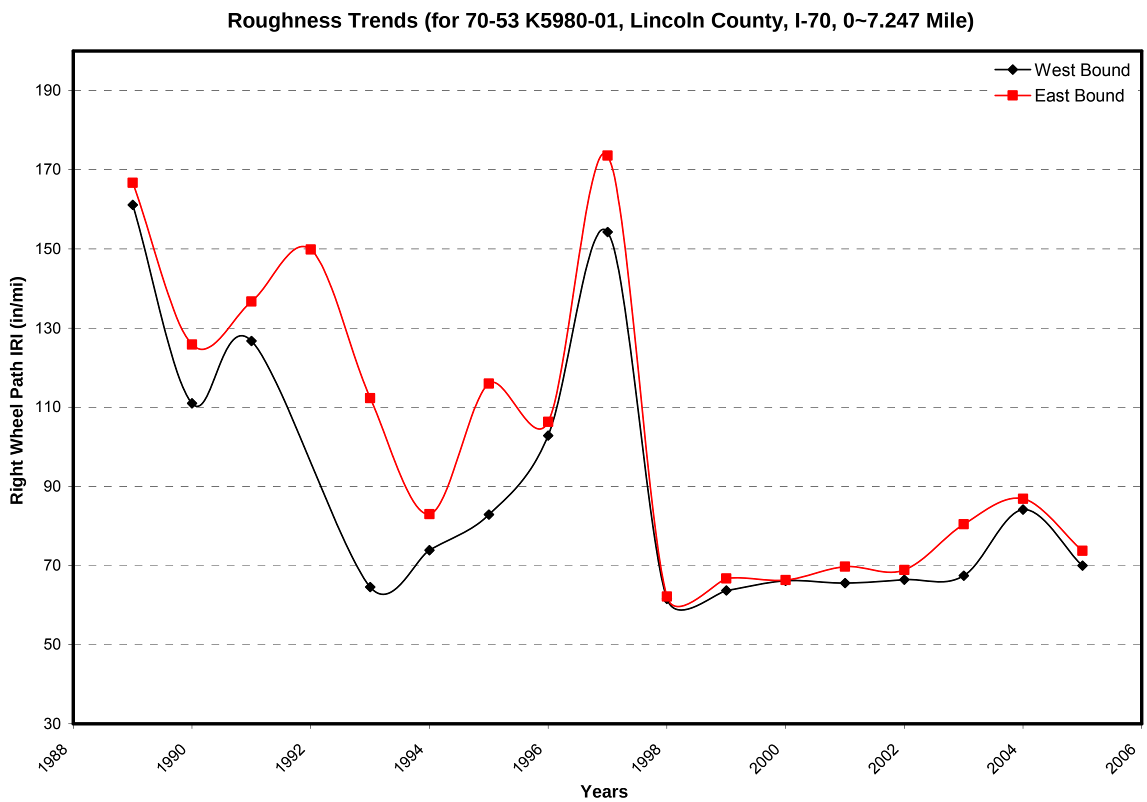


Figure 13: K-5981-01, completion date 1999 with a 70% improvement



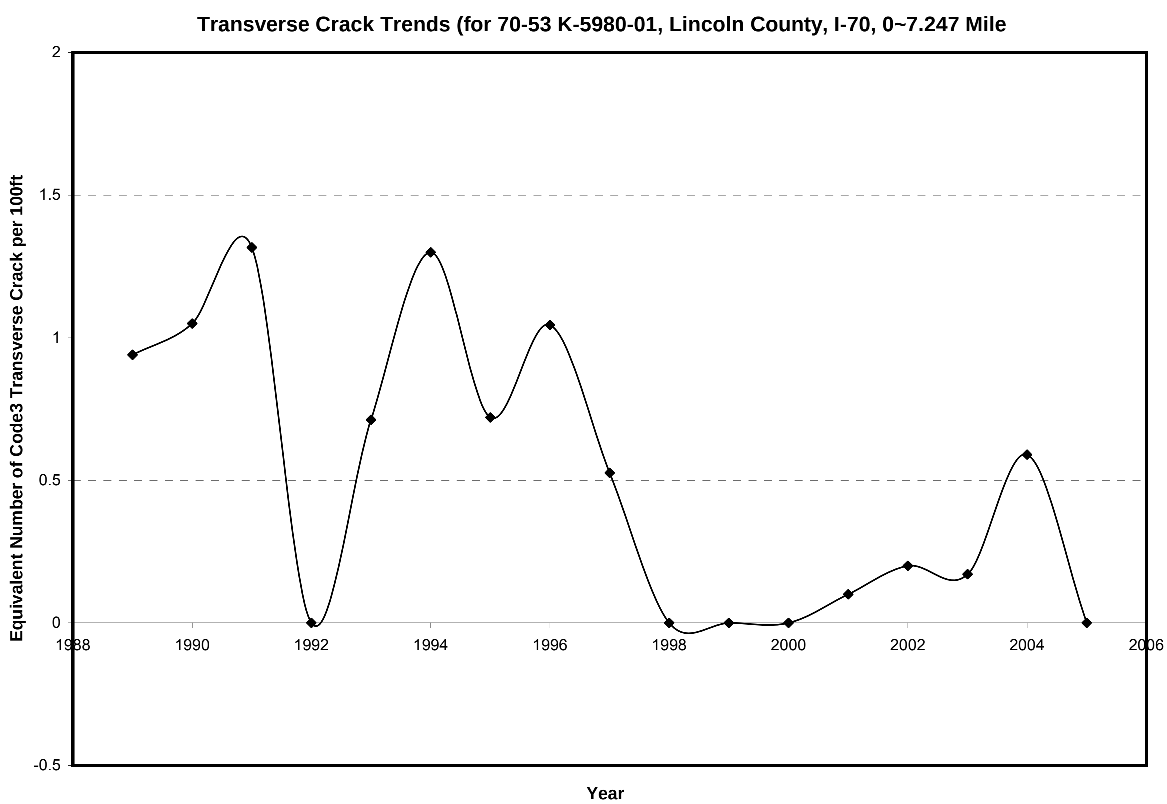
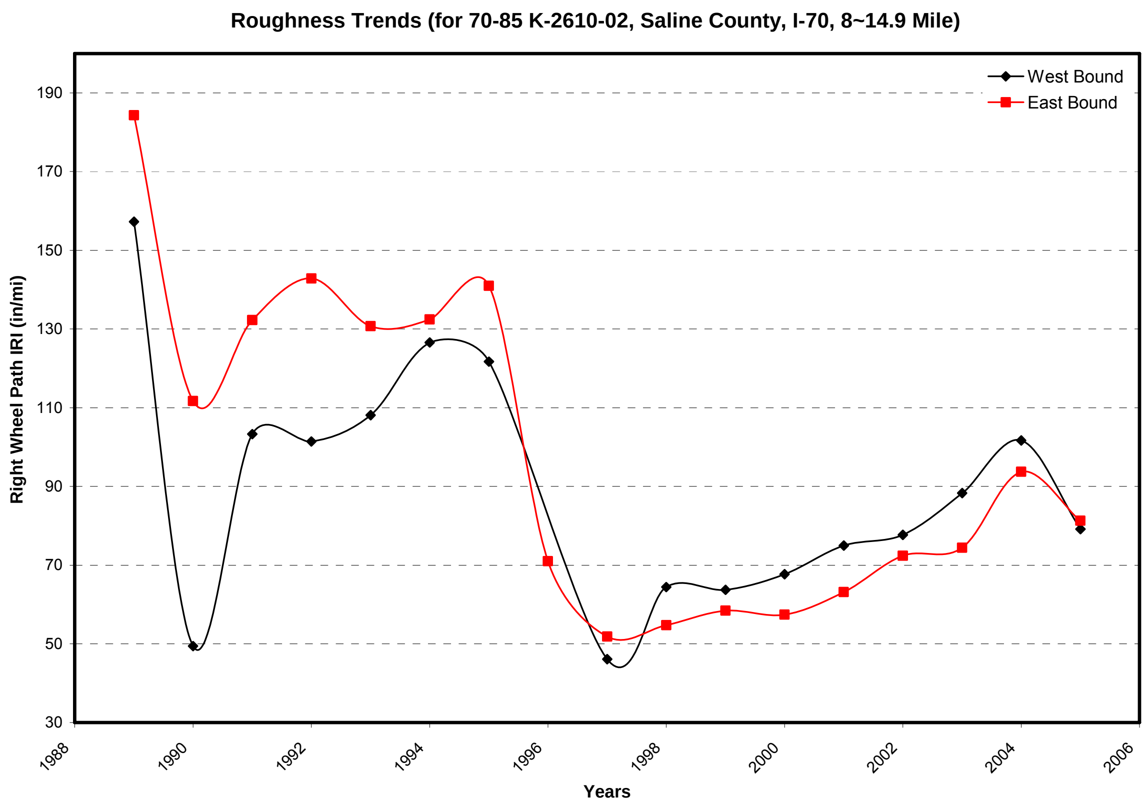


Figure 14: K-5980-01, completion date 1998 with a 63% improvement



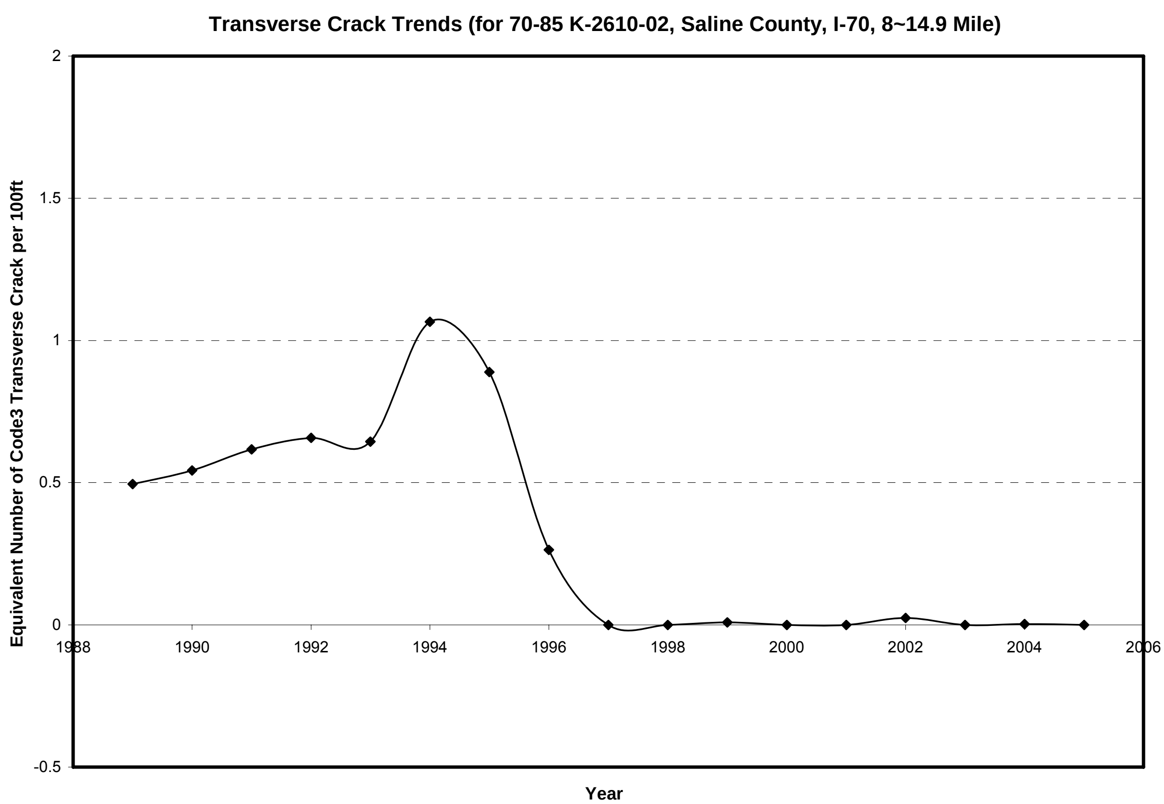
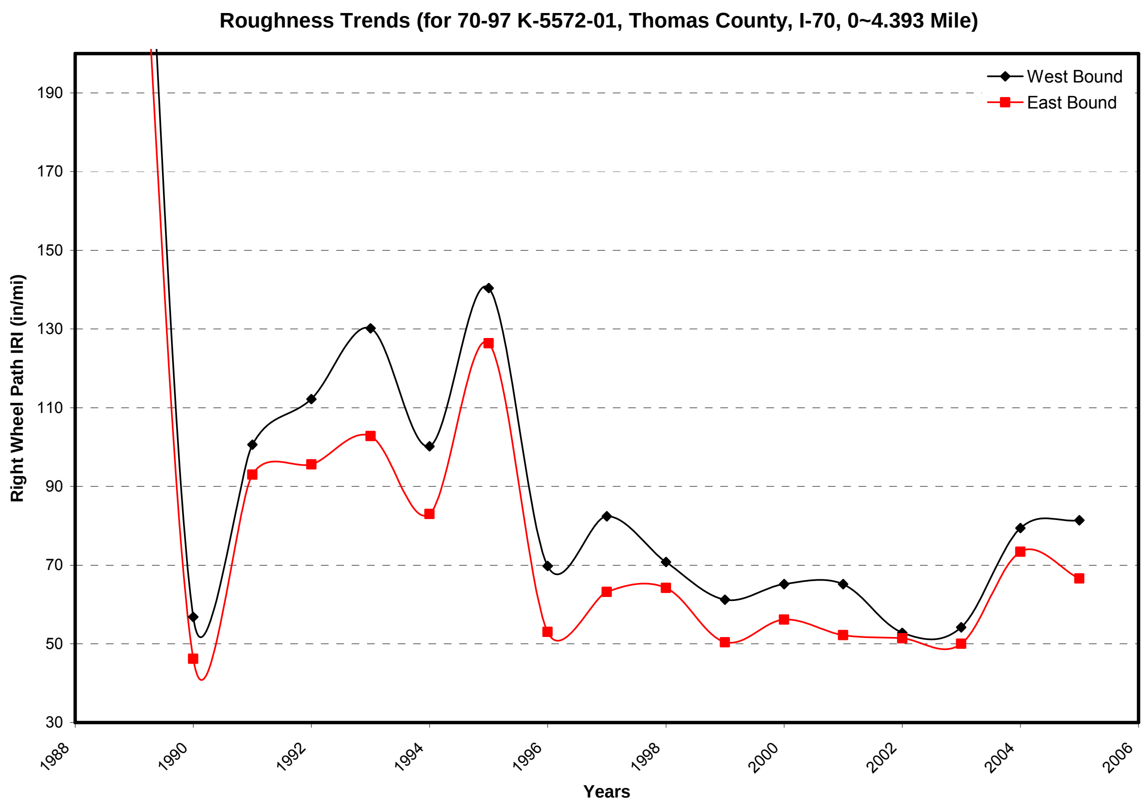


Figure 15: K-2610-02, completion date 1997 with a 64% improvement



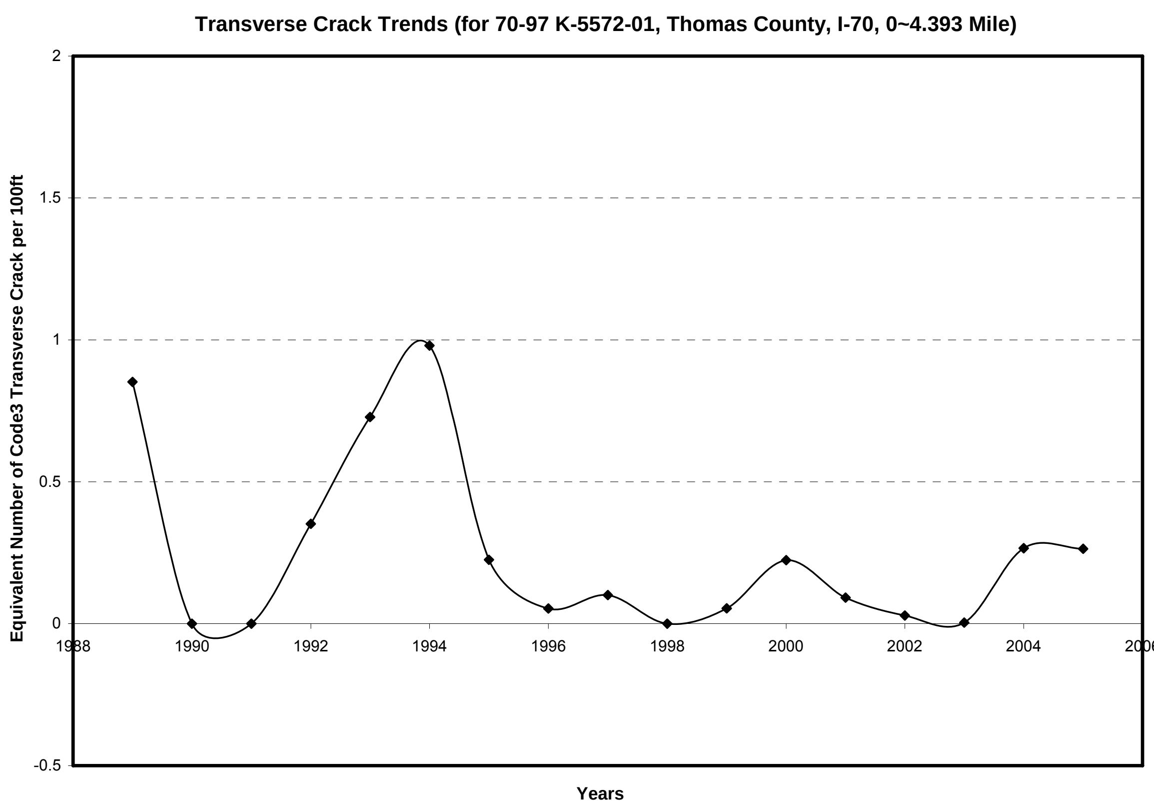
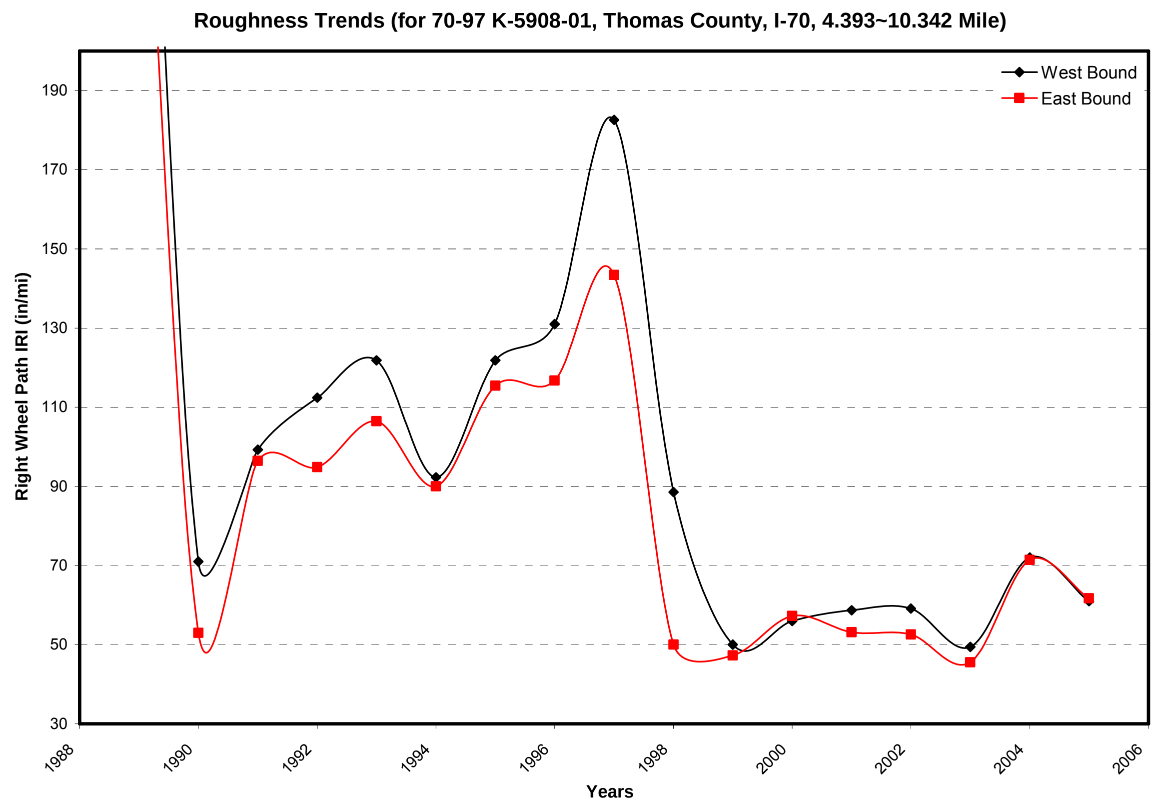


Figure 16: K-5572-01, completion date 1996 with a 56% improvement



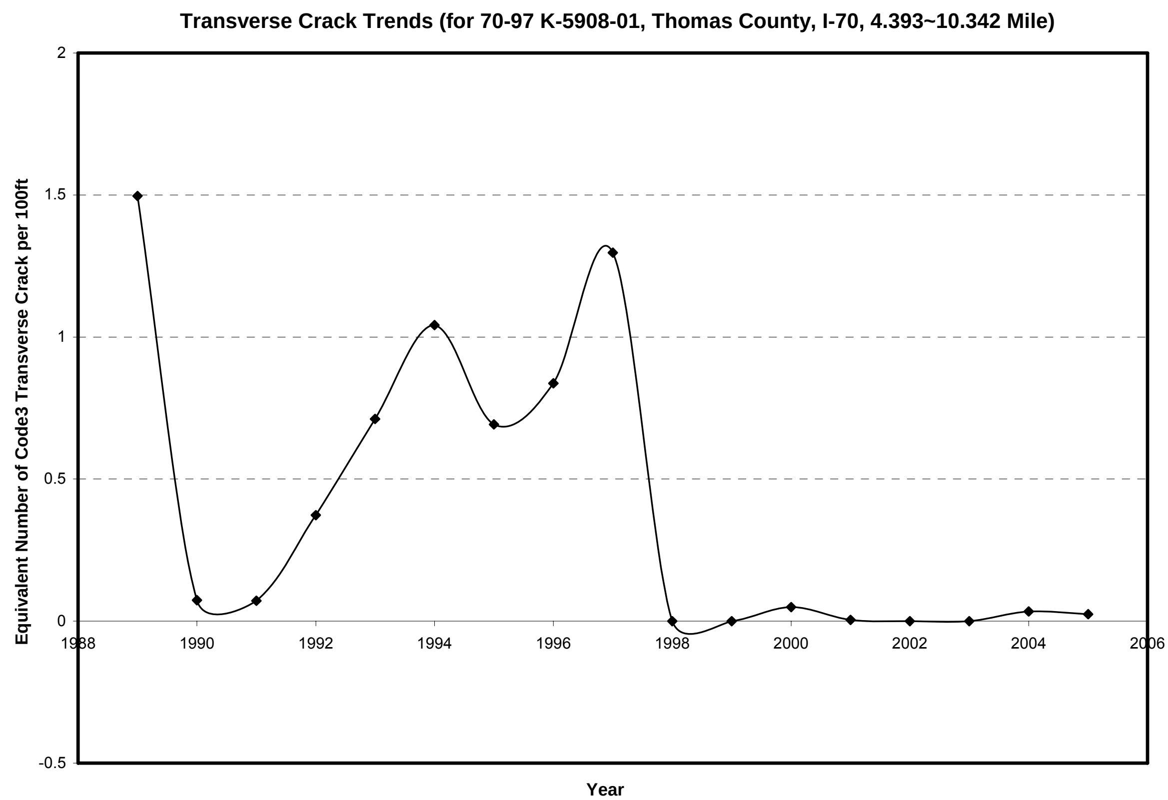
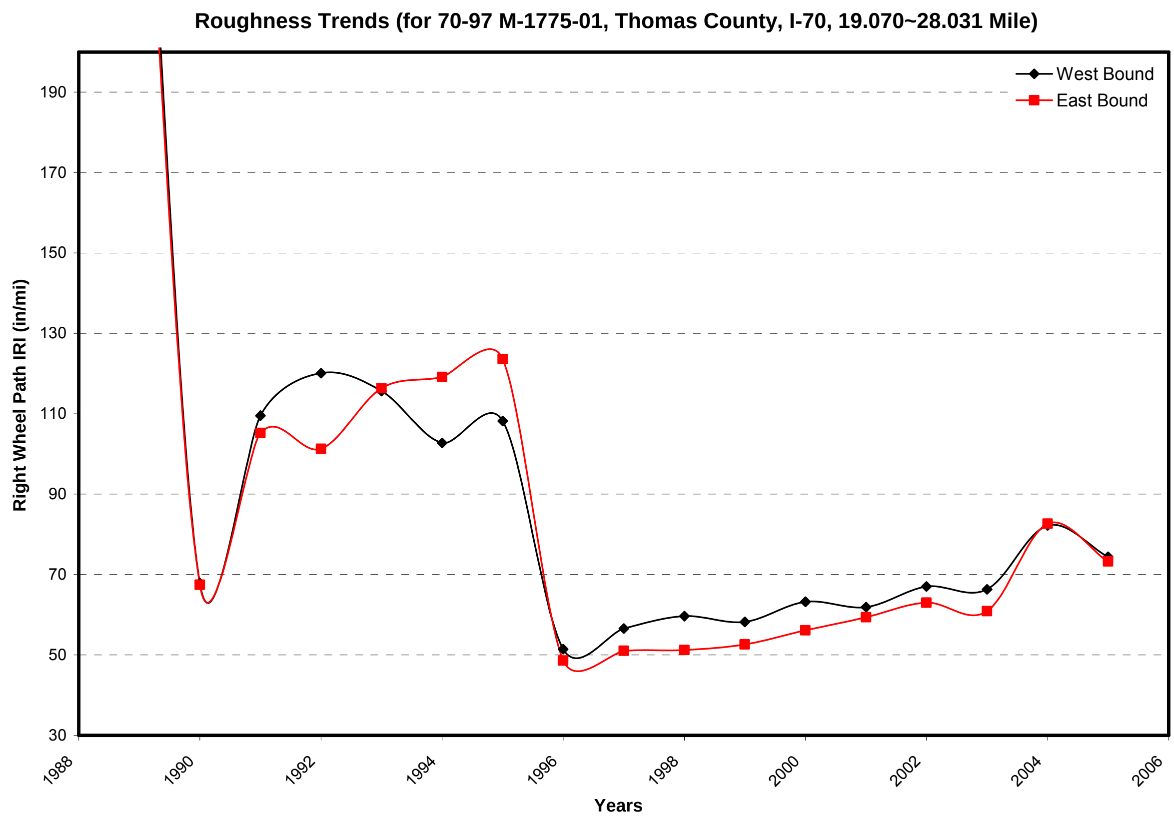


Figure 17: K-5908-01, completion date 1998 with a 71% improvement



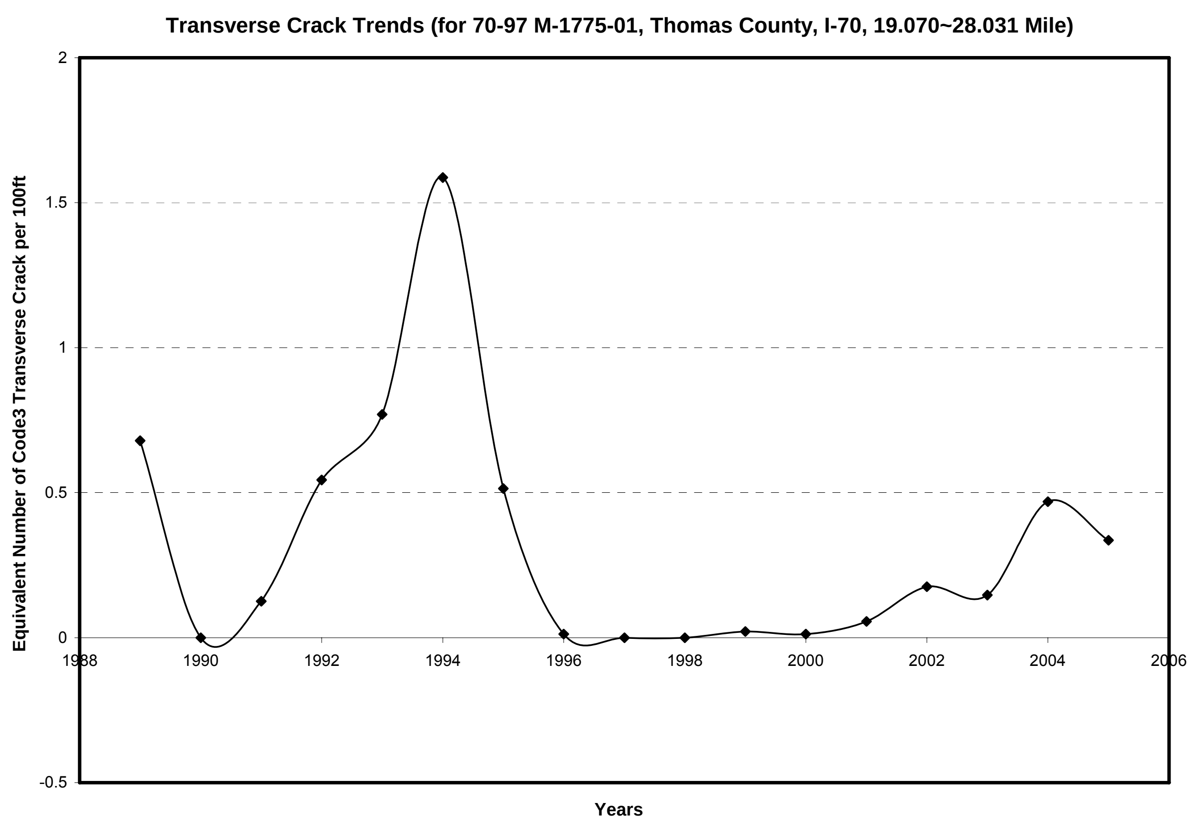
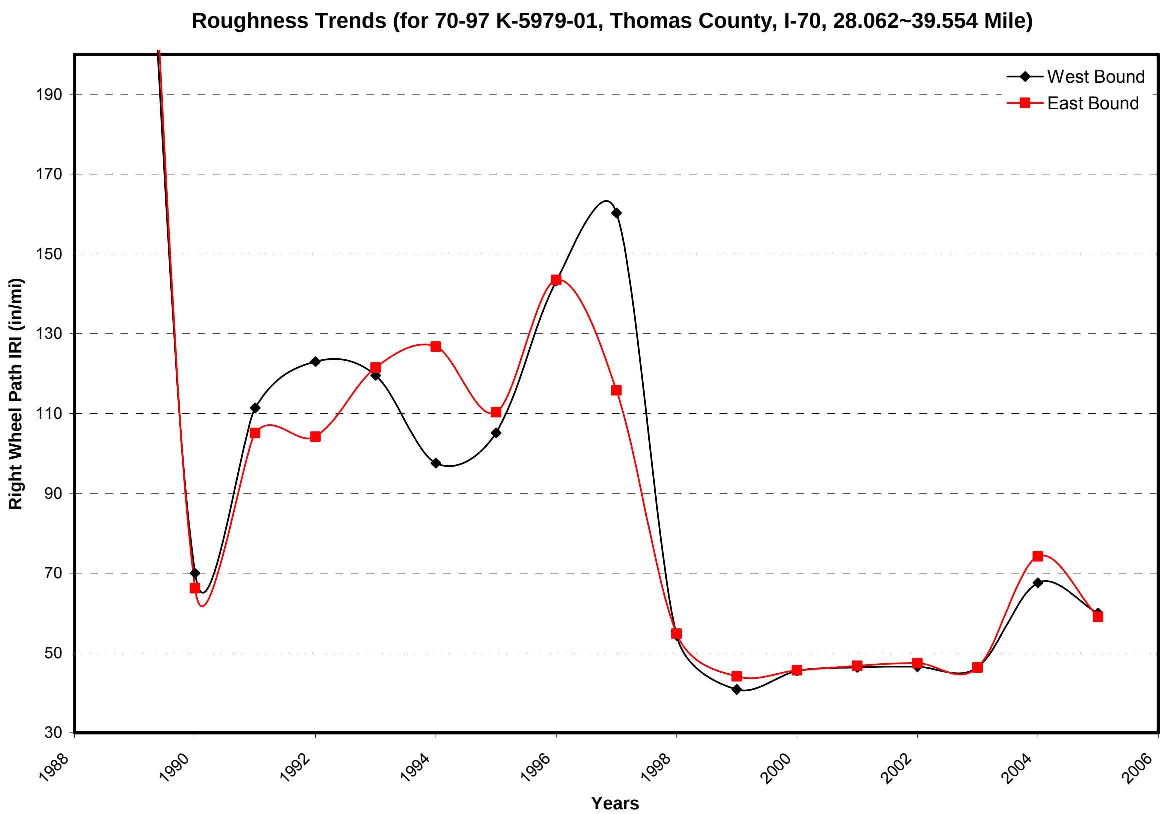


Figure 18: M-1775-01, completion date 1996 with a 60% improvement



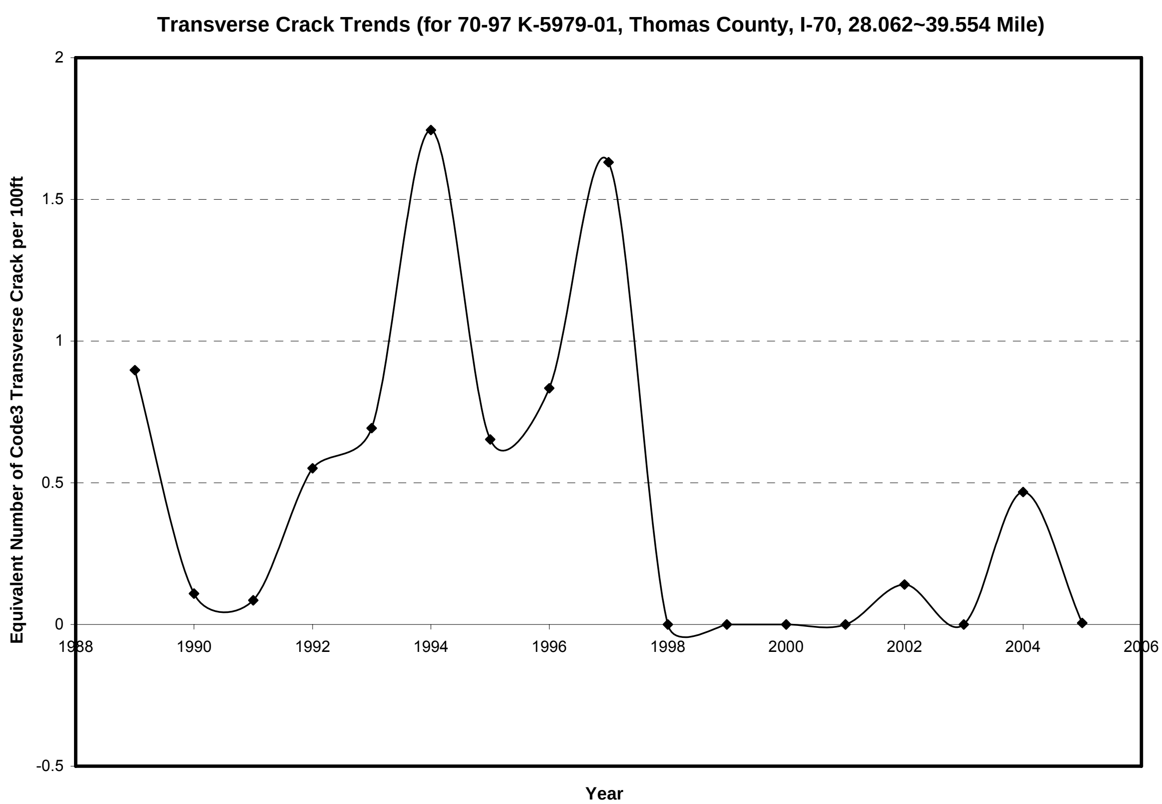


Figure 19: K-5979-01, completion date 1998 with a 75% improvement

CONCLUSIONS

The bang from the transverse cracking is gone on I-70 west of Salina. The FASI technique seems to have been the most successful rehabilitation method, resulting in improved highway smoothness. The injected fly ash slurry has resulted in the elimination of the transverse crack depressions for up to 12 years. The major conclusions that can be drawn from the study may be summarized as follows:

1. Using FASI to fill the voids under the existing pavement, followed by cold milling and overlaying with hot mix asphalt, has provided the benefit of retarding reflective cracking on ten sections of I-70 in western Kansas. This method can extend pavement service life and reduce future maintenance costs.
2. FASI was identified as an effective crack filling procedure. Filling the cracks and reducing or eliminating the depression would greatly improve ride and safety. It would reduce the wear on vehicle suspension and preserve existing pavement by reducing the water intrusion in the crack and reducing the impact loads created by vehicles bouncing through the depression.
3. FASI has proven to be a cost effective maintenance action for pavements with depressed wide cracks.
4. The IRI ride numbers on I-70 west of Salina have greatly improved overall since use of the FASI action began in 1988. The appearance of reflective cracking has been delayed and the severity reduced significantly.
5. Some of the pavement performance improvements are also due to the 4” CIR & HMA overlays used in conjunction with FASI.

RECOMMENDATIONS

The following recommendations are considered pertinent to the results of this research investigation:

1. Further comprehensive testing of cracked and uncracked pavement sections should be undertaken to develop a better understanding of actual thermal effects on stress, strain, and stiffness values.
2. A comprehensive evaluation of preventive and remedial maintenance procedures should be conducted to establish the conditions under which the various procedures perform best and should be considered useful in extending the life of a pavement if applied at the right time. The effects of various crack sealing procedures on different thicknesses of bituminous overlays should also be determined.
3. Cracks in asphalt pavements should be repaired as soon as possible after detection. Well-defined cracks with no secondary cracking should be sealed to prevent the incursion of water and non-compressible materials.
4. A field and laboratory investigation of pavement materials and highway features should be conducted in order to determine and evaluate the various factors that influence transverse cracking. Asphalt chemistry and aggregate properties should also be considered in the evaluation.
5. Cracks and depressions should be studied and inventoried each year. This would provide a means to historically watch and study the crack problems in order to help bring the problems to the attention of management.

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APPENDIX A

KANSAS DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION:

CRACK FILLING - FLY ASH SLURRY INJECTION

KANSAS DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION TO THE
STANDARD SPECIFICATIONS, EDITION OF 1990

NOTE: This special provision is generally written in the imperative mood. The subject, "the *Contractor*" is implied. Also implied in this language are "*shall*", "*shall be*", or similar words and phrases. The word "*will*" generally pertains to decisions or actions of the Kansas Department of Transportation.

CRACK FILLING - FLY ASH SLURRY INJECTION

1.0 DESCRIPTION.

Inject a fly ash slurry grout through holes drilled in the pavement to fill cracks.

Bid Item	**Unit**
Fly Ash (Slurry Injection)	Ton
Injection Holes	Each

2.0 MATERIALS.

(a) Provide materials that comply with the requirements of **Division 1000**:

Fly Ash (Class C) .... **Subsection 2005** (**Special Provision 90P-191**, latest revision)
Water .... **Subsection 2401**
Portland Cement .... **Subsection 2001**
Admixture for Set Retardation .... As Approved by the Engineer

(b) Composition of Fly Ash Slurry.

Provide a fly ash slurry grout consisting of fly ash, water and cement, or at the Contractors' option, necessary admixtures for set retardation may be used in lieu of cement. Use sufficient water to achieve fluidity. Fluidity of the grout when measured in accordance with ASTM C 939 must have a time of efflux between 9 and 15 seconds. Submit a mix design for the fly ash slurry to the Engineer for approval. Provide the following information:

(1) Proportions of all materials used.
(2) Source and type of fly ash.
(3) Source and type of cement, if used.
(4) Brand name and type of retarder, if used.
(5) Compressive strengths of test specimens.

(c) Strength Requirements.

The Department will mold a set of 3 test cylinders for each 100 cubic yards of fly ash slurry grout used. One cylinder will be tested on the 3rd day, the second cylinder on the 7th day and the third cylinder will be laboratory cured and held in reserve to verify any questionable cylinder breaks. The grout shall meet the following strength requirements:

Minimum 3-Day Compressive Strength ...... 200 psi
Minimum 7-Day Compressive Strength ...... 400 psi

(d) Initial Set.

Evaluate the material that has been placed by checking in injection hole and overflow. If the material has not achieved an initial set (hardened to a point where it can be stepped on without sticking) within 2 hours, cease operations until the cause of the problem can be determined and corrected by a change in material or mix design. The 2-hour time is flexible. It may take slightly longer than 2 hours in cold weather or considerably less when it is hot.

3.0 CONSTRUCTION REQUIREMENTS.

(a) Equipment.

(1) Grout Plant: Use a grout plant consisting of a positive displacement cement injection pump and a high speed colloidal mixing machine. The mixing machine shall operate between 800 and 2000 rpm, creating a high shearing action and subsequent pressure release to make a homogeneous mixture.

(2) Drilling: Use an air compressor and rock drills or other devices capable of drilling the injection holes through the pavement.

(b) Injection Holes. Drill a minimum of 2 holes per 12 feet of crack length. Drill the holes 6 to 12 inches from the crack to be filled. Place the holes either on alternating sides of the crack or on the same side of crack. The Engineer will approve the location of the injection holes, and will determine if additional holes are required to successfully fill the cracks. Drill the injection holes no larger than 2 inches in diameter, drill vertically and round, and drill to depth sufficient to penetrate the cavity to be filled.

(c) Crack Filling. Pump the fly ash slurry into the injection holes to completely fill the existing cracks. Temporarily plug an adjacent hole if doing so will force material into the crack. Monitor the operation so that the pavement is not lifted and the crack is not overfilled. Provide positive means of monitoring pavement lift; the Contractor's method shall be approved by the Engineer. Make corrections to the joints that were lifted and produced an unacceptable ride.

Before final acceptance, clean up and remove all waste material from the surrounding areas.

When pavement lift creates an unsafe condition, maintain the lane closure until acceptable corrections are completed.

(d) Weather Limitations. Do not inject the fly ash slurry into existing cracks if the air temperature is 32°F or below, or if the ground is frozen. Do not place the slurry if it is raining or when weather conditions otherwise prevent the proper handling and placing of materials.

4.0 MEASUREMENT AND PAYMENT.

The Engineer will measure the fly ash by the ton of material placed on the project. Water and admixtures are not measured separately, but are subsidiary to the fly ash. Injection holes are measured by the number of holes drilled. Monitoring for pavement lift is not measured separately, but is subsidiary to the injection holes.

The Engineer will pay for "Fly Ash (Slurry Injection)" and "Injection Holes" at the Contract unit price which is full compensation for the specified work. No adjustment in Contract unit prices is made regardless of the amount of underruns or overruns. No payment for “Fly Ash

(Slurry Injection)" or "Injection Holes" is made if the grout fails to meet the requirements of **subsection 2.0(c)**.

01-05-98 C&M/M&R (DW/JLC)

DEPARTMENT OF TRANSPORTATION

AD ASTRA PER ASPERA

· KANSAS ·