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FINAL REPORT

FULL DEPTH BITUMINOUS RECYCLING OF I-70, THOMAS COUNTY, KANSAS

Glenn A. Fager, P.E.
Kansas Department of Transportation

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16 Abstract

In 1990, 13 full depth asphalt pavement test sections were built on a portion of I-70 in Thomas County, Kansas. Various combinations of hot mix and cold recycle mixes with different additives were used to build the test sections. Two of the test sections were constructed with a reduced pavement thickness in order to determine how long the thin pavement could withstand the heavy loading of interstate traffic. At least three test sections employed the use of cold recycle material using Class C fly ash, CMS-1 with hydrated lime, and CMS-1 only. The top layers were hot mix, but both an AC-20 and polymerized or modified asphalt was used as the liquid binder.

The test sections were monitored over a period of 11 years. The top layer had severe micro-cracking which was probably due to further hardening of the AC-20. Two seals were placed over the surface in order to prevent raveling. The cost of each test section was determined and the life on at least four of the test sections could be determined. On five of the test sections the pavement life could only be estimated. Based on the initial construction cost and life of each test section, an annual cost of each test section could be determined or estimated.

Based on these annual costs, the field crack/rut survey and Falling Weight Deflectometer measurement, the thicker full depth hot mix test section was judged to perform the best. The thin full depth hot mix had the highest annual cost. The life of these thin sections were determined to be three to five years and were not economically feasible as a means of interstate reconstruction. The cold recycled sections with the different additives performed quite well, with the CMS-1 with and without lime having a lower annual cost than the fly ash section.

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Prepared by

Glenn A. Fager, P.E.
Kansas Department of Transportation

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ABSTRACT

In 1990, 13 full depth asphalt pavement test sections were built on a portion of I-70 in Thomas County, Kansas. Various combinations of hot mix and cold recycle mixes with different additives were used to build the test sections. Two of the test sections were constructed with a reduced pavement thickness in order to determine how long the thin pavement could with stand the heavy loading of interstate traffic. At least three test sections employed the use of cold recycle material using Class C fly ash, CMS-1 with hydrated lime, and CMS-1 only. The top layers were hot mix, but both an AC-20 and polymerized or modified asphalt was used as the liquid binder.

The test sections were monitored over a period of 11 years. The top layer had severe micro-cracking which was probably due to further hardening of the AC-20. Two seals were placed over the surface in order to prevent raveling. The cost of each test section was determined and the life on at least four of the test sections could be determined. On five of the test sections the pavement life could only be estimated. Based on the initial construction cost and life of each test section, an annual cost of each test section could be determined or estimated.

Based on these annual costs, the field crack/rut survey and Falling Weight Deflectometer measurement, the thicker full depth hot mix test section was judged to perform the best. The thin full depth hot mix had the highest annual cost. The life of these thin sections were determined to be three to five years and were not economically feasible as a means of interstate reconstruction. The cold recycled sections with the different additives performed quite well, with the CMS-1 with and without lime having a lower annual cost than the fly ash section.

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Chapter 1

Introduction

Certain bituminous pavements on I-70, particularly those in the western part of the state, developed transverse cracks very early in their life. Wide transverse cracks were reported west of Colby in 1972, five years after the pavement was constructed. These transverse cracks were depressed a distance of one foot on each side of the crack in the wheelpaths. Later overlays temporarily smoothed out the pavement, but reflection cracks developed shortly after the overlay was placed. Attempts have been made by maintenance forces and use of contract maintenance to patch and seal the cracks. Those efforts have been limited in success. Effective crack repair techniques to prevent crack reoccurrence are not possible with today's technology. However, slurry injection has worked very well in delaying the reoccurrence of the reflection crack. The experimental features (test sections) were assigned a National Experimental Project Tabulation (NEPT) number of KS 90-02.

1.1 Background

In 1987, concrete overlays, full depth recycling and bituminous reconstruction were procedures that had been used to rehabilitate cracked bituminous pavements. While each method either eliminates or retards the cracking all were very expensive. A previous rehabilitation project in Sherman County cost $700,000 per mile for a new Portland Cement Concrete (PCC) pavement. A full depth hot recycled bituminous pavement was estimated in 1987, to cost $630,000 per mile. However, a combination of cold and hot recycled pavement section was estimated to cost between $390,000 and $460,000 per mile depending on the structure used. With this in mind, Kansas Department of Transportation's (KDOT) management proposed to construct under project number 70-97 K-2348-01 several alternates to evaluate the constructability of techniques that should prevent thermal and reflection cracks, the economy of these techniques, and their ability to minimize the detrimental effects of fatigue damage, rutting, and nonload associated cracking. Full depth hot recycling had been demonstrated as an effective means of removing the crack pattern in bituminous pavements that reflect through overlays. Due to the expense associated with hot recycling and the generation of waste material, it was not a very economical method for rehabilitation. Cold recycling on the other hand removes the crack pattern, generates no waste, and costs considerably less. However, a hot-mix overlay structural section is required to protect the weaker cold recycled mixture. As traffic loading increases the protective overlay must become thicker.

Therefore, the concept for the reconstruction of the Colby I-70 project was starting to take form in 1987. Although the wide transfer cracks had been present since 1972, no extensive field or laboratory investigation had been conducted. During the rest of 1987, materials (cores, etc.) were obtained from both sides of I-70 west of Colby.

Extensive coring, pavement removal, and subgrade sampling was conducted. The pavement removal was conducted to determine if stripping was present. Very little visual evidence of stripping was found. Cores were obtained for depth, density, asphalt properties, aggregate gradation and strength. The average depth of the pavement was 14.9 inches in the eastbound (EB) lanes and 15.1 inches in the westbound (WB) lanes. The pavement thickness had been identified as having three distinct layers. The top layer consisted primarily of a BM-2 mixture placed in 1973/1974. The ¾-inch BM-1 placed in 1973/1974 had been essentially removed by the milling in 1983/1984. Indirect resilient modulus tests were conducted on representative samples from each layer. The average modulus was 280,000 psi for the top layer, 370,000 psi for the middle layer and 170,000 psi for the bottom layer. The bottom layer consists of aggregates composed of sand and gravel. The top and middle layers consist of aggregates composed of crushed limestone and some sand and gravel. The viscosity of the recovered binder in the top layer averaged 5600 poises whereas the middle layer averaged 32,000 poises. The viscosity of the asphalt binder as well as the aggregate (crushed vs. uncrushed) had a large bearing on the modulus of the mixture. A target viscosity for new asphalt was 2000 poises. The stiffer the asphalt, the greater the strength of the mix. However, there is a greater potential for low temperature cracking with stiffer asphalt. Two different sub grade soils were encountered during the investigation. They were classified as a silty loam and a silty clay loam, with plasticity indices (PI) of 7 and 18. Dynaflect deflection tests were used to back calculate the subgrade modulus. The results ranged between 14,000 to 26,000 psi. Resilient modulus tests were conducted on undistributed samples, and the results ranged between 8,000 psi and 32,000 psi. The in-situ moisture content in the subgrade was measured at about 18 percent. The moisture in the subgrade appeared to be related to the proximity of a crack in the pavement. At reference mile 42.3, the cores were taken in a crack and in a non-cracked area. The moisture content in the subgrade at a crack averaged about 18 percent, but it decreased to 9 percent in the non-cracked area.

The visual distress survey showed two to three transverse cracks per 100-foot section. The depth of rutting was dependent on when the surface had been milled but generally the rutting was approximately ½ inch. The past milling actions appear to be more related to the depressions that result at the transverse cracks than the rutting.

The problems associated with this pavement appear to be directly related to the aging (stiffening) of the asphalt binder. The aging is not a process that appears to stop with time.

Therefore, actions that cover up (overlays) or treat only portions (crack repair) of the surface do not address the problem. Structural capacity is not a problem based on the analysis of the deflection and pavement distress data. Since the cause of the distress is primarily materials related, the solution is to address the material characteristics. The primary objective will be to eliminate the crack pattern and/or change the material or mechanical characteristics.

Four basic alternate test sections were recommended for construction in order to measure what effect each would have on the cost and pavement performance. One side (EB or WB) had additional test sections within the primary test sections. These were constructed to evaluate the effects of changes in additives, i.e., polymerized asphalts, fly ash, etc. The four primary test sections were as follows:

1. ¾-inch BM-1T + 13-inch Hot Recycle + 6-inch Subgrade Modification (1½ miles)
2. ¾-inch BM-1T + 5-inch Hot Recycle + 8-inch Cold Recycle + 6-inch Subgrade Modification (4 miles)
3. ¾-inch BM-1T + 3-inch Hot Recycle + 10-inch Cold Recycle + 6-inch Subgrade Modification (2 miles)
4. ¾-inch BM-1T + 3-inch Hot Recycle + 6-inch Cold Recycle + 4-inch Pulverized RAP (½ mile)

The shoulders consisted of a Seal + 4-inch Hot Recycle + 6-inch Cold Recycle.

1.2 Expected Performance

Based on an analysis for fatigue damage, the alternates were expected to have design lives from 2½ to 10 years. The shortest period could be increased to 4¼ years depending on the actual value of the structural layer coefficient of the cold recycled material. Depending on the type of asphalt (or more importantly its properties) that was used, distress other than fatigue related damage might develop as early as 6 years in any of the alternates. However, modified asphalt was used to a limited extent to determine its effect on nonload associated cracking. The estimate of fatigue life for each alternate was as follows:

Alternate	Design Life
1.	10 years
2.	9 years
3.	6 to 8½ years
4.	3½ to 4¼ years

The design life for alternates 3 and 4 fell short of the desired eight year design period due to the expected consolidation of the cold recycled material. The consolidation would result in rutting and possibly fatigue cracking in the hot mix layer. After the cold mix consolidates a 2½-inch overlay for alternate 4 should extend the life of the pavement for at least 8 more years. If alternate 3 does not meet its expected design life, a 1½-inch overlay will be needed to extend its life at least 8 more years.

Chapter 2

Construction

The first contact letting was on May 17, 1990. The actual bids were considerably higher than the estimate; therefore the contract was not approved. The test sections were changed so that most of them would be constructed in the westbound lanes. Figures 1 and 2 show the location of the test sections as finally constructed. There were some additional changes that will be explained later in this report. The reconstruction of the rest areas was dropped from the main letting and awarded in a separate contract.

The second contract letting was on June 21, 1990. The contract was approved on July 3, 1990, and a Notice to Proceed was issued on July 6, 1990. A completion date was set for October 11, 1991. The $10.8 million contract called for a complete reconstruction of I-70 from Colby, Kansas, west to the junction of US-24. The 8.64 mile project also incorporated the reconstruction of two interchanges but no rest areas were now included. There was one main contractor and ten subcontractors.

Construction began almost immediately, as did the problems. Due to the fact that the test sections were in the westbound lanes, the construction was first focused on the eastbound lanes. After the entire pavement had been removed down to the subgrade, problems with the underlying support structure became obvious. Moisture had saturated the subgrade to the point that construction equipment was getting stuck and could not adequately maneuver. Negotiations with the contractor determined that the best solution was to add approximately 12 percent Type C fly ash with no additional water. Moisture already present in the subgrade reacted with the fly ash, thereby giving a stronger subgrade from which to build the rest of the roadway.

Construction progressed slowly during the remainder of 1990, until the winter shutdown of October 15, 1990. Except for the surface course, about 4.7 miles of the eastbound lanes were completed.

In 1991, traffic signs were moved on February 28th, and construction began in the westbound section on March 15th. The plan now was to complete the westbound sections and then return to finish the eastbound section.

At this time, the decision was made that the westbound subgrade would also be treated with fly ash. During 1990, belly-dump trucks were used to distribute the ash, but during 1991 pressurized trucks were used. Large mixers incorporated the fly ash into the subgrade to a depth of 8 inches, and 16 inches in some wet locations. This revised design seemed to work quite well and allowed the construction activities to proceed as originally planned. Once the subgrade was stabilized, the entire test sections were constructed in the westbound lanes as indicated in Figure 2.1.

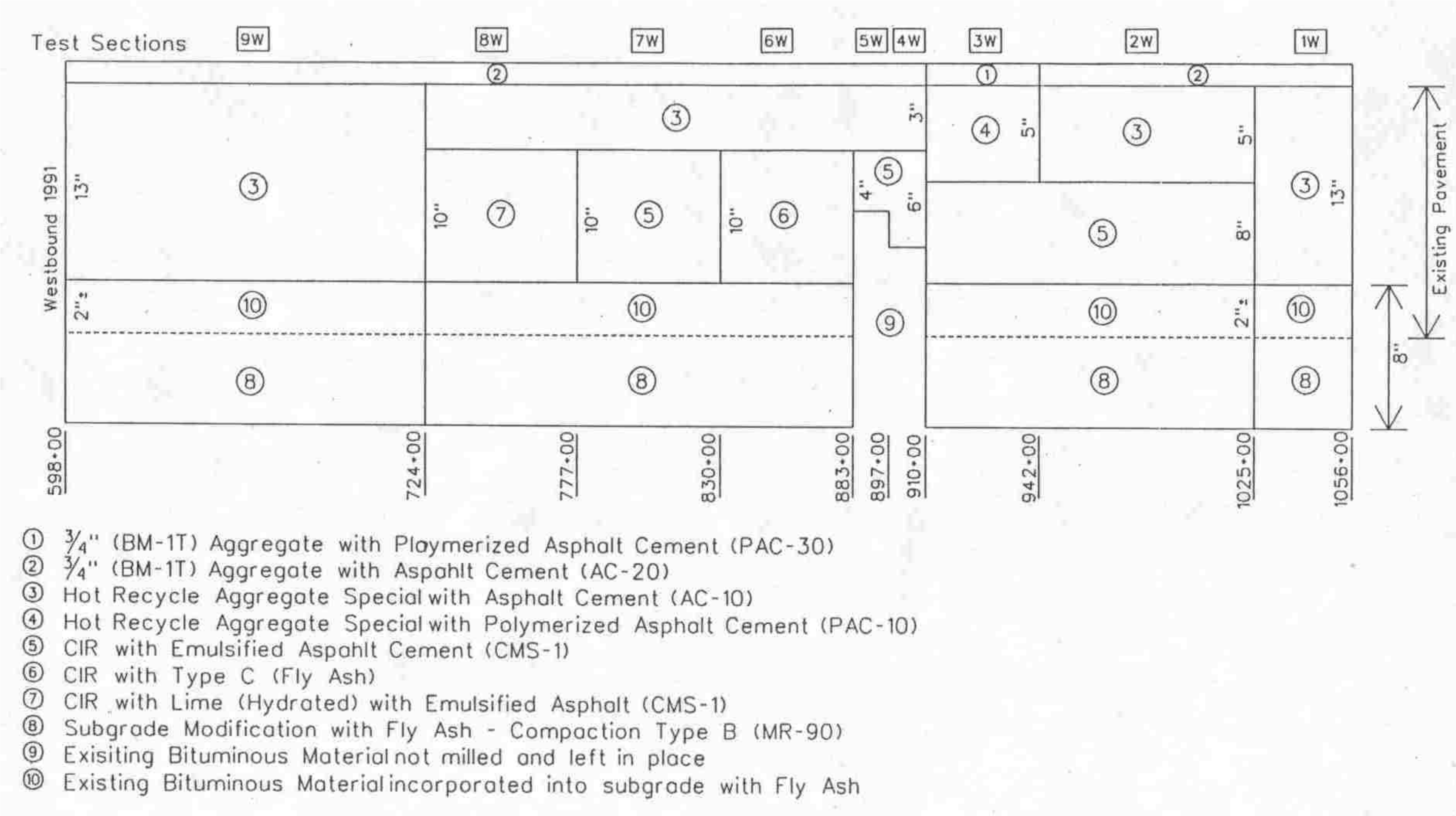

FIGURE 2.1: Westbound Test Section Locations

The cold in-place recycle (CIR) was completed in 4-inch lifts approximately 12 feet wide. A paving train was used, but most of the material had to be removed from the project as the depth varied from 4 to 10 inches. Most of the mainline CIR averaged 8 inches in depth. Problems that occurred with the CIR specifications as written were as follows:

1. CIR specifications did not address multi-lift construction.

2. Test strip target densities that required measurements at a minimum temperature of 90° Fahrenheit were impossible to determine because many days early in the construction season the temperatures remained below 90° Fahrenheit but above the 55° Fahrenheit temperature established as the minimum at which work could precede. A target density that could be established with a modified Marshall compactor or an approved rolling pattern was determined to be a better method.

3. Payment for the CIR would be more administratively manageable if it was calculated by the square yard rather than by the station. Different test sections contained different portions of CIR with multiple lifts, which made it difficult to determine completion of each station.

The biggest difficulty came when 1 percent hydrated lime was added to the cold recycle mix. A stationary 9-foot pug mill was used with the cold recycle material that was transported to the plant site. The lime was added as a slurry with three parts lime to seven parts water by weight. This occurred in the front part of the pugmill. As the recycled asphalt pavement (RAP) became coated with the lime slurry, 1 percent CMS-1 asphaltic emulsion was also added as a final treatment. No major problems occurred with the laydown and compaction as the material laid very well and became stiffer with time. The major problem came after initial lay down. The specifications required the free moisture content to be below 1½ percent before the next lift could be laid. The lime treated cold recycled material as placed contained 5 to 7 percent moisture. It took 6 weeks to complete one lane mile, which was much too long to be practical. Again, the cold recycle specifications did not address multiple lifts.

In contrast to the lime treated section, the section incorporating the fly ash was constructed as expected. The Type C fly ash came from Sutherland, Nebraska, and was shipped in pressurized tanker trucks. The 7 percent fly ash was placed by blowing it into a "V" notch in the windrow. The process worked very well and the lessons learned the previous year certainly aided in the shipment and handling of the product. The paving train collected the material and added about 8 percent water. The material was immediately laid using a conventional asphalt paving machine. The mixture compacted well and there was no attempt to remove excess moisture because it was needed for the hydration process. However, some problems were encountered as follows:

1. Once water was added to the fly ash/RAP mixture, it set up extremely fast. The contractor had 15-30 minutes to lay and compact it. Therefore, the rollers absolutely had to remain very close to the paving train.
2. No patching or leveling was possible in the low spots because a blade damaged the fly ash base and destroyed its strength. Once reworked, the fly ash base does not re-heal or regain its initial strength.

3. The pug mill and equipment needed to be cleaned regularly because the material tends to "cake up" and eventually the pugmill will seize.

4. Mechanical breakdowns of the paving train create major logistic problems because the mixture sets up quickly in the windrow and/or the pavers.

The laid material set up very nicely and formed a very strong base on which to lay the hot mix. No major problems were reported in the test sections incorporating the polymerized asphalts. Both a PAC-10 and PAC-30 were used as planned.

The hot recycling continued throughout the year in the sections that were not being cold recycled or where the cold recycled had just been completed. Low air voids were encountered and the mix was changed and redesigned several times. Originally, the mix incorporated 40 percent RAP and 60 percent virgin aggregate (40/60). A 35/65 aggregate blend and a 30/70 blend were tried with much improved results. Of course, with the higher virgin aggregate content, the cost of the mix increased. Budget limitations prevented the aggregate blend from going beyond the 30/70 blend and other alternatives were tried. The asphalt content in the hot recycle was reduced to be as low as possible without causing other problems (premature pavement cracking, raveling, higher water permeability). Two problems that seemed to aggravate the hot recycle mix characteristics were bag house fines and changes in the RAP stockpile. The specifications allowed bag house fines to be returned to the mix. If these fines had been disposed by another means, the mix air voids would have been higher. Variability in the RAP stockpile also caused some variation in the final mix asphalt content. The gradation of the RAP was also finer than originally calculated. Beyond changing the RAP/virgin aggregate blend and the added asphalt content, there were no further field adjustments that could be made without incurring an additional major expense.

Wheel path rutting in the eastbound lanes constructed in 1990 precipitated changes made in the hot recycled mix. A detailed investigation was conducted to determine why ½ inch of rutting developed in the eastbound wheelpaths from Station 860+00 to 1025+00. The report concluded that the cause of the wheelpath rutting to be <u>both</u> the cold and hot recycle mixes. An excerpt of the conclusion in that report is as follows:

> "The cold recycle layer has undergone substantial compaction since it was constructed. A new Special Provision is now in place to control the compaction of cold recycling mixes. The test strip has been replaced with a standard 50 blow Marshall compaction of cold recycle material warmed to 110 degrees Fahrenheit. This should help to prevent rutting on future projects. The hot recycle mix was determined, by the gyratory test method, to be unstable or marginally stable. This was caused by degradation of the RAP. Corrections to the RAP:virgin ratio on this project seemed to have solved the stability problems. This experimental project was constructed according to the 1990 KDOT Standard Specifications. As a result of this project, some changes have been made to our Standard Specifications. A problem was found with a finer RAP than anticipated, and corrections were made in the RAP:virgin ratio that has appeared to solve the rutting problem. Corrections were made in the placement of the cold recycle layer, which resulted in higher densities at the time of construction. In order to repair the existing roadway, the existing ruts were removed by cold milling. The section was then overlaid with 1" BM-1T. We feel the efforts made during the construction of this experimental project, and the lessons learned, were cost effective. The corrective action should produce an acceptable surface for the traveling public. This experimental project will be evaluated for several years. If problems develop in the future, corrective action will be undertaken."

One of the lessons learned was applied to the rest of the cold recycle construction in the eastbound lane. Most of the westbound cold recycling was complete when it was determined that low densities were causing the wheel path rutting. But, the rest of the eastbound lane needed reconstruction. Specifications could not change the density requirements for the cold recycle as the contract was already fixed in place. Field changes in the hot recycle had already been implemented as far as possible, but it was still felt necessary to increase the stability in the cold recycle lifts. The simplest and easiest way to increase the strength was to add fly ash to the top 4 inches of an 8-inch cold recycle base so, during the last part of the 1991 construction season (when the rest of the eastbound lanes were constructed) fly ash was also added to the top 4 inches of the cold recycle section. Figure 2.2 shows this last change, which was implemented between Sta. 632+00 and 810+00.

When the eastbound section was back under construction, the westbound sections carried the diverted traffic head to head. Within one day under traffic, sections 4W and 5W were showing definite signs of early failure in spot locations. Some maintenance patching was immediately applied and the sections monitored for further development. The untimely failure did not continue beyond the original spot failures.

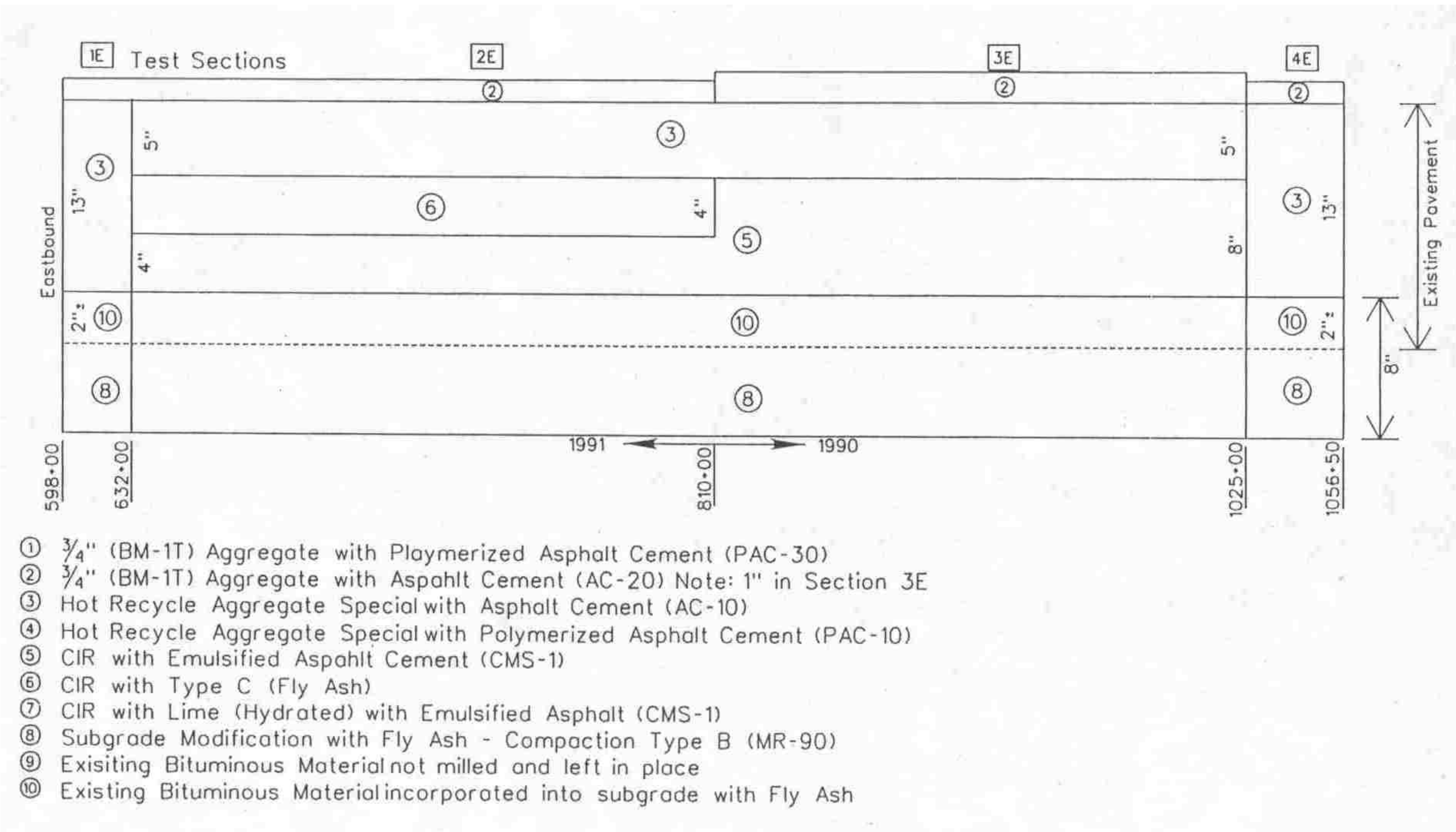

FIGURE 2.2: Eastbound Test Section Locations

After all of the cold and hot recycling was completed, traffic was placed on both sides of the interstate. The bridgework and intersections, although not a part of this research project, had been previously completed in sequence to the lane changes. The only work remaining was some surface milling, a BM-1T surface course overlay, and some grass seeding. After the ruts were removed from the eastbound section constructed in 1990, a BM-1T surface course was constructed under traffic. The eastbound driving lanes, from Sta. 810+00 to Sta. 1025+00, received a 1-inch surface course. The rest of the project received only a ¾-inch surface course.

The total project was 99 percent complete with traffic using both the eastbound and westbound lanes by October 1991. The grass seeding was not completed as it was too late in the year. It was completed in 1992. During the entire project construction, there were 14 bituminous mix designs made and 11 change orders approved.

2.1 Cost Data

The total project cost was $ 12,676,967.43 and overrun of 17 percent of the original estimate. The cost of each section is presented in Table 2.1. These costs did not include such items as mobilization, paint stripping, field laboratory, signing, traffic control, and grass seeding. The cost was calculated on a price per mile basis for comparative purposes and included both the main roadway and shoulders. All subgrade, asphalt milling, seals, and tack coats were included in the costs of each test section. The main construction materials (lime, asphalt, emulsions, fly ash, etc.) were figured into the totals.

TABLE 2.1: Cost Data and Analysis

TEST SECTION	DESCRIPTION	INITIAL COST ($/Mile)	ANNUAL COST ($/Mile/Year)
1W	¾-inch BM-1T 13-inch Hot Recycle	588,000	58,800 or less
2W	¾-inch BM-1T 5-inch Hot Recycle 8-inc CIR	459,000	57,375
3W	¾-inch BM-1T 5-inch Hot Recycle (PAC-10) 8-inch CIR(CMS-1)	476,000	47,600 or less
4W	¾" BM-1T 3" Hot Recycle 6" CIR (CMS-1) 4 ½ Year Life	341,000	85,250
5W	¾" BM-1T 3" Hot Recycle 4" CIR (CMS-1) 3 ½ Year Life	321,000	80,250
6W	¾" BM-1T 3" Hot Recycle 10" CIR (Fly Ash)	439,000	54,875
7W	¾" BM-1T 3" Hot Recycle 10" CIR (CMS-1)	430,000	43,000 or less
8W	¾" BM-1T 3" Hot Recycle 10" CIR (Lime & CMS-1)	448,000	44,800 or less
9W	¾" BM-1T 13" Hot Recycle	588,000	58,800 or less
1E	¾" BM-1T 13" Hot Recycle	588,000	
2E	¾" BM-1T 5" Hot Recycle 4" CIR (Fly Ash) 4" CIR (CMS-1)	466,000	
3E	1" BM-1T 5" Hot Recycle 8" CIR (CMS-1)	470,000	
4E	¾" BM-1T 13 " Hot Recycle	588,000	

Chapter 3

After Construction Performance

The project was monitored for several years by periodic field visits, crack surveys, and falling weight deflectometer (FWD) measurements. Field inspections revealed that the surface showed micro-cracking, which was probably caused by the hard asphalt in the mix. An AC-20 had been used in the BM-1T surface course. To address this distress and raveling that also occurred, a conventional seal was placed over the entire project in 1995. The conventional seal placed during 1995 severely raveled and needed replacement to provide adequate protection for the road. In 1997, a latex-modified slurry seal was placed on the entire project and its performance has been satisfactory through 2001. These seals made intermediate crack surveys unreliable for life cycle comparisons and the project had to be monitored through general visual inspections and FWD data collection. The project was inspected on the following dates:

1. September 16, 1993
2. July 27, 1995
3. July 22, 1997
4. August 25, 1998
5. September 13, 2000 (Formal Survey)

In the 2000 inspection, a formal crack survey was conducted and the results are presented in Tables 2 and 3. After four years, test sections 4W, and 5W failed in 1995 due to extensive patching in these sections. In 1999, after eight years, test Sections 2W and 6W failed, also due to extensive patching. Test Section 9W performed the best and according to the distress survey is still performing satisfactorily after 10 years of service. No measurable rutting was observed in any of the westbound test sections that are still performing satisfactorily.

FWD data was collected and the results for the last four years are presented in Table 4. A structural number (SN) was calculated for each section. Note that Sections 4W and 5W have been patched and therefore will show an artificially higher SN. With no patching the deflections from the FWD would be higher, resulting in a lower pavement modulus, which in turn would result in a lower SN.

TABLE 3.1: Crack and Rut Survey for Westbound I-70

Section	Description	Year	Cracking (Feet) Transverse	Cracking (Feet) Longitudinal	Rutting	Remarks
2W	¾-inch BM-1T 5-inch Hot Recycle 8-inch CIR (CMS-1) 8-inch Submod				None	(Small amount of patching in 1993 & 1995. Test Section failed in 1999 because of extensive patching) **Pavement Life= 8 Years**
3W	¾-inch BM-1T 5-inch Hot Recycle (PAC-10) 8-inch CIR (CMS-1) 8-inch Submod	2001	307	1747	0.10	
4W	¾-inch BM-1T 3-inch Hot Recycle 6-inch CIR (CMS-1) 6-inch Existing				None	(Test Section has failed in 1995 because of extensive Patching) **Pavement Life= 4 Years**
5W	¾-inch BM-1T 3-inch Hot Recycle 4-inch CIR (CMS-1) 8-inch Existing				None	(Small patching in 1993. Test Section failed in 1995 because of extensive patching) **Pavement life = 4 Years**
6W	¾-inch BM-1T 3-inch Hot Recycle 10-inch CIR (Fly Ash) 8-inch Submod				None	(Test Section has failed in 1999 because of extensive patching) **Pavement Life = 8 Years**
7W	¾-inch BM-1T 3-inch Hot Recycle 10-inch CIR (CMS-1) 8-inch Submod	2001	215	33	0.11	(Small patching was noticied in 1995)
8W	¾-inch BM-1T 3-inch Hot Recycle 10-inch CIR (Lime & CMS-1) 8-inch Submod	2001	150	784	0.08	
9W	¾-inch BM-1T 13-inch Hot Recycle 8-inch Submod	2001	7	0	0.10	

TABLE 3.2: Crack and Rut Survey for Eastbound I-70

Section	Description	Year	Cracking (Feet)		Rutting	Remarks
			Transverse	Longitudinal		
2E	¾-inch BM-1T 5-inch Hot Recycle 4-inch CIR (Fly Ash) 4-inch CIR (CMS-1) 8-inch Submod	2001	479	2590	0.13	
3E	1-inch BM-1T 5-inch Hot Recycle 8-inch CIR (CMS-1) 8-inch Submod	2001	112	590	0.23	

TABLE 3.3: Falling Weight Deflectometer (FWD) Data

Section	Description	Year	Unadjusted Subgrade Modulus (psi)	Pavement Modulus (psi)	Effective Structural Number
2W	¾-inchBM-1T	2000	21,000	128,000	3.22
	5-inch Hot Recycle	1999	17,000	119,000	3.22
	8-inch CIR (CMS-1)	1998	19,000	114,000	3.06
	8-inch Submod	1997	19,000	99,000	2.91
3W	¾-inch BM-1T	2000	17,000	118,000	3.12
	5-inch Hot Recycle (PAC-10)	1999	15,300	133,000	3.38
	8-inch CIR (CMS-1)	1998	17,000	131,000	3.24
	8-inch Submod	1997	17,000	116,000	3.11
4W	¾-inch BM-1T	2000	16,000	80,000	3.51
	3-inch Hot Recycle	1999	14,000	81,000	3.25
	6-inch CIR (CMS-1)	1998	15,000	79,000	3.12
	6-inch Existing	1997	15,000	71,000	3.00
5W	¾-inch BM-1T	2000	16,000	97,000	3.35
	3-inch Hot Recycle	1999	14,000	90,000	3.36
	4-inch CIR (CMS-1)	1998	15,000	86,000	3.21
	8-inch Existing	1997	14,000	65,000	2.92
6W	¾-inch BM-1T	2000	11,000	60,000	2.48
	3-inch Hot Recycle	1999	12,000	81,000	2.83
	10-inch CIR (Fly Ash)	1998	14,000	82,000	2.73
	8-inch Submod	1997	13,000	69,000	2.58
7W	¾-inch BM-1T	2000	18,000	106,000	3.01
	3-inch Hot Recycle	1999	16,000	97,000	3.03
	10-inch CIR (CMS-1)	1998	18,000	106,000	3.02
	8-inch Submod	1997	17,000	96,000	2.92
8W	¾-inch BM-1T	2000	17,000	126,000	3.20
	3-inch Hot Recycle	1999	15,000	150,000	3.50
	10-inch CIR (Lime & CMS-1)	1998	17,000	145,000	3.35
	8-inch Submod	1997	16,000	130,000	3.23
9W	¾-inch BM-1T	2000	18,000	516,000	5.13
	13-inch Hot Recycle	1999	14,000	614,000	5.58
	8-inch Submod	1998	16,000	487,000	5.01
		1997	16,000	466,000	4.96
2E	¾-inch BM-1T	2000	10,000	79,000	2.75
	5-inch Hot Recycle	1999	11,000	117,000	3.23
	4-inch CIR (Fly Ash)	1998	12,000	101,000	2.97
	4-inch CIR (CMS-1)	1997	12,000	106,000	3.02
	8-inch Submod				
3E	1-inch BM-1T	2000	12,000	85,000	2.85
	5-inch Hot Recycle	1999	12,000	88,000	2.98
	8-inch CIR (CMS-1)	1998	13,000	106,000	3.08
	8-inch Submod	1997	13,000	100,000	3.01

3.1 Data Analysis

There are basically two field measurements that could be used to determine the performance of each test section: first, the FWD data and second, final crack surveys along with field observations. The FWD data from Table 3.3 indicates that from 1997 through 2000 there is no trend in the SN from one year to the next. Normally, the SN would decrease with time. The SN for the thick hot recycle section (9W) was high and remained high when compared with the other test sections. The lowest SN was in the section that employed the use of fly ash. By 2000 this section (6W) had dropped to a SN level where the road would be a candidate for reconstruction or some other corrective action. All of the other sections maintained an adequate SN of 3.0 to 3.5.

The crack surveys and field observations revealed a somewhat similar trend. The useful life of a test section was determined by the age when it reached 5 percent or more patching. The short, thin "reduced life" sections (4W and 5W) were determined to have a life of four years based on this criterion. The section with fly ash (6W) and one of the sections with hot recycle with CMS-1 (CIR) had a life of eight years. All of the other sections were performing satisfactorily after 10 years of service although some have cracking. The thicker 13-inch hot mix section (9W) is performing quite well with no cracking nor rutting after 10 years of service life.

An economic analysis in its simplest form was applied to each test section. The cost of each section had been computed, and the life or minimum life was determined. Excluding maintenance cost, inflation, and interest rates, the annual cost of each section could be determined on a cost per mile per year basis. The results are presented in the last column of Table 3.1. The reduced life sections only lasted four years as predicted in the early planning stages of the project. The initial costs for these (4W and 5W) were less than all of the other sections, but on a life cycle cost basis they were the most expensive. The two sections that lasted eight years (6W and 2W) have the next highest life cycle cost. All of the other sections are performing satisfactory and are still in service. Based on expected service lives, their life cycle costs will be less. All of the CIR sections have developed cracks, and probably will deteriorate further in the near future. Based on the FWD data and the absence of any cracking, the lowest life cycle cost is expected for section 9W or the 13-inch hot mix section. After 10 years of service the 13-inch full depth hot recycle section annual life cycle cost is expected to be the least when compared to all the other sections and its overall performance (cracking and rutting) is superior to the other sections.

Chapter 4

Summary and Conclusions

4.1 Summary

In summary, the thin (reduced life) test sections performed the worse when compared to all of the other sections. Initial construction costs of the thin sections were certainly cheaper, but the overall life cycle costs are higher. The most cost-effective section was the full depth 13-inch hot recycle section. Based on the performance data from this study, the CMS-1 with lime was best performing additive combination to be used.

4.2 Conclusions

1. The thin reduced life sections performed satisfactory for the expected four years but had the highest life cycle cost.
2. Based on the FWD data, crack and rut surveys, the full depth (13-inch) hot recycle pavement design is the best performing of all the other test sections. At the end of the study this pavement was still in service, but after 10 years the annual life cycle cost is the lowest of all test sections investigated.
3. Cold in-place recycled pavement (CIR) pavement with CMS-1 and lime performed satisfactorily and had an acceptable life cycle cost.