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16. Abstract

This project focused on evaluating the effectiveness of the microcracking concept for reducing shrinkage cracking in cement-treated bases (CTB). Microcracking can be defined as the application of several vibratory roller passes to the cement-treated base at a short curing stage, typically after 1 to 3 days, to create a fine network of cracks. Previous report 0-4502-1 described activities undertaken during the first two years of this research project to validate and develop guidelines for the application of microcracking. This report (4502-2) details results from continued monitoring of field test sections, along with details from new microcracking test sites constructed between September 2004 and August 2005. Based upon the results, this report presents revised guidelines as an Appendix for the application of microcracking to reduce the risk of reflective cracking problems from cement-treated bases. Even if implemented on only 25 percent of Texas Department of Transportation CTB projects, it is estimated microcracking could save the department approximately $1.5 million in net present value (NPV) costs through reductions in future crack sealing operations. Given the range of observed effectiveness of microcracking, full implementation could save between $3.3 and $8.6 million in yearly NPV costs.

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CONTINUED EVALUATION OF MICROCRACKING IN TEXAS

by

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Report 0-4502-2
Project 0-4502
Project Title: Microcracking Stabilized Bases during
Construction to Minimize Shrinkage

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

November 2005

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

The contents of this report reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. The researcher in charge was Stephen Sebesta.

ACKNOWLEDGMENTS

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- Mike Arellano, P.E.
- Magdy Mikhail, P.E.
- Andrew Wimsatt, P.E.

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CHAPTER 1

UPDATE OF SH 47 PERFORMANCE

SUMMARY

The SH 47 test sites were constructed in the spring of 2002 and include approximately 4.5 lane miles of cement-treated base (CTB) divided among five rehabilitated sections. During construction, TxDOT microcracked all the sections after a curing time of one to three days. As of summer 2005, the performance is still good, particularly in the three northbound sites and the second southbound site. The first southbound site has the worst condition, with 1404 total linear feet of cracking in the 2307 foot section, or approximately 2 feet of cracking per 100 square feet of pavement. In several of the test sections, some longitudinal cracking appears due to edge drying, and some cracking also appears resultant from the longitudinal construction joint. Regardless, through time some cracking has started to show up in the hot-mix asphalt (HMA) layers in all the sections.

DETAILS OF TEST SECTIONS AS OF SUMMER 2005

Report 0-4502-1 documented the structure and layout of the test sections (*1*). A final survey of the sections was performed in August 2005 under this project. Table 1.1 summarizes the findings, with details of each test section following.

Table 1.1. Crack Statistics Summary for SH 47 from Summer 2005.

Section	Crack Lengths (feet)			Crack Length per 100 Feet Pavement (3000 square feet)		
	Transverse	Longitudinal	Total	Transverse	Longitudinal	Total
NB STA 1362.60 to 1346.76	10	315	325	0.63	19.89	20.52
NB STA 1175.16 to 1154.04	0	98	98	0.00	4.64	4.64
NB STA 1127.64 to 1098.85	16	0	16	0.56	0.00	0.56
SB STA 2142.52 to 2165.59	155	1249	1404	6.90	55.56	62.46
SB STA 2281.84 to 2310.88	9	153	162	0.31	5.27	5.58

NB STA 1362.60 to 1346.76

In this section, two locations of longitudinal cracking exist, with one transverse crack in the outside lane (OL). Figure 1.1 shows the first longitudinal crack and the transverse crack, which intersects the longitudinal crack. Given the straightness and location of this 180 foot longitudinal crack, it may be resultant from a construction joint in the base.

Figure 1.1. First Longitudinal and Transverse Crack on SH 47 NB.

The second longitudinal crack in this section exists in the inside lane near the end of the section and is 135 feet long. Figure 1.2 shows the crack. Given its meandering nature, it is not believed to be due to a construction joint.

Figure 1.2. Second Longitudinal Crack in SH 47 NB.

NB STA 1175.16 to 1154.04

In this section, no transverse cracking exists. A 60 foot longitudinal crack exists from 1163.70 to 1163.10 in the inside lane, shown in Figure 1.3. Given its location, this crack may be at a longitudinal construction joint in the base. A second longitudinal crack 38 feet in length, shown in Figure 1.4, exists in the inside lane from 1161.33 to 1160.95. This crack may be caused by shrinkage cracking in the subgrade reflecting up through the base and HMA layers.

Figure 1.3. Longitudinal Crack in SH 47 NB from STA 1163.70 to 1163.10.

Figure 1.4. Longitudinal Crack in SH 47 NB from STA 1161.33 to 1160.95.

NB STA 1127.64 to 1098.85

In this section a transverse crack 16 feet in length exists at STA 1124.84. This crack appears classical of reflective cracking from the CTB. Figure 1.5 shows the crack.

Figure 1.5. Transverse Crack at STA 1124.84 in SH 47 NB.

SB STA 2142.52 to 2165.59

This section exhibits the worst performance of all the SH 47 test sites. This site has approximately 3 times the amount of cracking per area of pavement and approximately 11 times the transverse cracking as the next closest section in terms of crack statistics. Earlier surveys (*1*) showed a portion of this section had distress before any of the other sites. The location of the initial distress has worsened, and several other locations within the section now have visible distress in the HMA. Table 1.2 summarizes the distresses seen in this section, and Figures 1.6 through 1.17 show representative photos of the distresses.

Table 1.2. Cracking Summary of SH 47 SB from STA 2142.52 to 2165.59.

SH 47 SB Station	Crack Lengths (feet)		Comment
	Transverse	Longitudinal	
2142.52 to 2143.06	0	54	construction joint?
2143.50	23	0	across most of pavement
2144.95	6	0	in shoulder
2144.80 to 2145.70	0	90	crack at HMA joint
2144.94 to 2145.66	20	85	initiation of block cracking in inside lane
2145.23	4	0	in shoulder
2145.23 to 2145.43	0	20	in outside lane ~ 2 feet from HMA joint
2146.68 to 2147.20	0	52	in outside lane near outside wheel path
2146.70 to 2149.18	0	248	edge cracking
2147.72 to 2147.86	0	14	in outside lane - construction joint?
2153.87	18	0	in shoulder
2154.49 to 2154.89	7	40	initiation of block cracking in shoulder and outside lane
2155.94 to 2156.92	14	237	all lanes and shoulder - location of earliest visible distress
2161.88 to 2162.99	52	264	start of block cracking; ~ 67 feet of longitudinal may be construction joint
2164.06 to 2164.86	11	145	start of block cracking; ~ 64 feet of longitudinal cracking may be construction joint

Figure 1.6. Distress on SH 47 SB from STA 2142.52 to 2143.06.

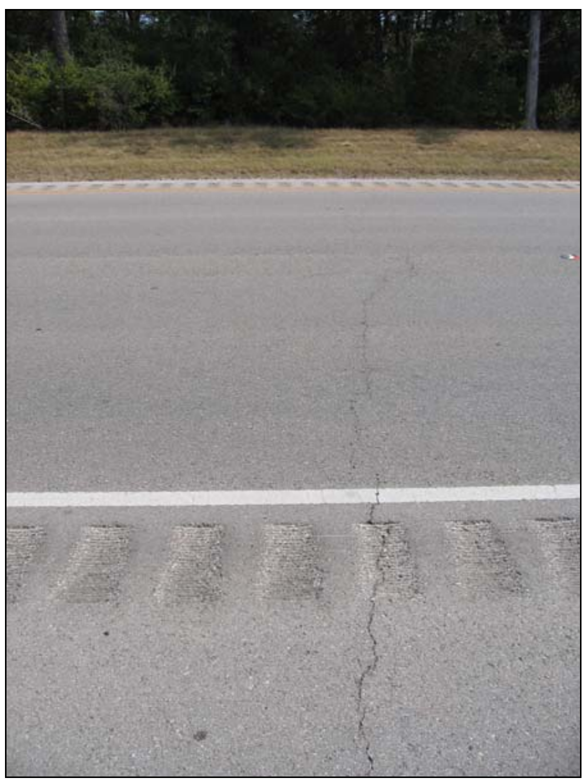


Figure 1.7. Transverse Crack on SH 47 SB at STA 2143.50.

Figure 1.8. Cracking in SH 47 SB from STA 2144.94 to 2145.66

Figure 1.9. Cracking in SH 47 OL from STA 2145.23 to 2145.43 (Joint crack from 2144.80 to 2145.70 also visible).

Figure 1.10. Longitudinal Crack in SH 47 SB OL from STA 2146.68 to 2147.20.

Figure 1.11. Edge Cracking in SH 47 IL from STA 2146.70 to 2149.18.

Figure 1.12. Longitudinal Cracking in SH 47 SB OL from STA 2147.72 to 2147.86.

Figure 1.13. Transverse Cracking in SH 47 SB at STA 2153.87.

Figure 1.14. Cracking in SH 47 SB from STA 2154.49 to 2154.89.

Figure 1.15. Cracking in SH 47 SB from STA 2155.94 to 2156.92.


Figure 1.16. Block Cracking in SH 47 SB from STA 2161.88 to 2162.99.


Figure 1.17. Cracking in SH 47 SB OL from STA 2146.06 to 2146.86.

SB STA 2281.84 to 2310.88

In this section the only distress noted was the initiation of block cracking in the outside lane from STA 2289.69 to 2290.11, shown in Figure 1.18, and a 94 foot longitudinal crack possibly resulting from the construction joint from 2289.79 to 2290.73.

Figure 1.18. Cracking in SH 47 SB from STA 2289.69 to 2290.11.

CONCLUSIONS FROM SH 47

In general the performance of the sections on SH 47 is good, with only one of the five test sections showing appreciable amounts of cracking after 3 years. In several cases a substantial amount of cracking is longitudinal and may be the result of the construction joint or cracking in the subgrade soil, and therefore not directly resultant of the CTB. The worst performing section is in the southbound travel direction from STA 2142.52 to 2165.59. Prior analysis discussed the possibility that this particular section may not have been microcracked enough, as no falling weight deflectometer (FWD) verification was performed during microcracking (*1*). Additionally, the possibility of differences in the crack resistance of the HMA exists since the northbound travel direction is surfaced with a different HMA mixture. However, the second southbound site currently exhibits some of the best performance of all the sections, casting doubt on the plausibility of the HMA accounting for the difference in cracking performance. While differences in the crack resistance of the HMA cannot be completely ruled out, currently the most plausible explanation is that the section may not have been adequately microcracked. This observation highlights the importance of process control when performing microcracking. TxDOT should try to make sure that some type of test device is available for monitoring the attainment of microcracking on field projects. When the FWD is not available, a portable FWD (PFWD) may provide a good alternative.

CHAPTER 2

PERFORMANCE UPDATE OF TEST SITES AT RIVERSIDE CAMPUS

SUMMARY

The test sites at Texas A&M's Riverside Campus constructed under this project in September 2003 continue to illustrate the effectiveness of microcracking. The treatments used and layout of the sites have been previously documented (*1*). These test sites revealed the best performance was obtained by using both current mixture design criteria (300 psi unconfined compressive strength [UCS] after seven days curing and meet moisture susceptibility criteria) and microcracking after two days curing. Additionally, in every case for any given treatment, reduced cement content has resulted in less cracking. The best performer with 4 percent cement has less than half the amount of cracking as the best performer with 8 percent cement.

CRACKING PERFORMANCE

Figures 2.1 and 2.2 show the cracking present at the test sites as of June 2005. Table 2.1 shows the cracking statistics of the test sites through time. Table 2.1 also shows the cracks occurring after application of the treatment, or "preventable" cracking, as of June 2005, and the percent change in cracking for each treatment as a percentage of the amount of cracking in the control (moist cured) section. These data show:

- With 4 percent cement, microcracking after two days resulted in the best performance.
- With 4 percent cement, microcracking always resulted in better crack performance than the control.
- With 4 percent cement, no significant difference in crack performance exists between the moist cured and prime cured.
- With 8 percent cement, microcracking always resulted in improved crack performance in terms of preventable cracking; however, the best cracking performance exists in sections microcracked at one day and three days curing. European researchers found that with high cement contents, two applications of microcracking were necessary, with the first application applied after one day curing, then a second application applied on the third or fourth day (*2*). It is hypothesized better performance on the section with 8 percent cement may have been obtained by performing two microcracking procedures.
- With 8 percent cement, the prime cured section exhibited much more cracking than the control.
- For any given treatment, the section with 4 percent cement exhibited less cracking than its counterpart site treated with 8 percent cement. Figure 2.3 illustrates this observation. However, with moist curing alone, the difference in crack performance between the two cement contents is minimal. A reduction in cement content alone is not enough to significantly improve crack performance.
- The best performer in 4 percent cement had less than half the amount of cracking as the best performer with 8 percent cement. Maintaining high cement content then applying microcracking does not optimize the cracking performance of CTB.

- Reduced cement contents combined with microcracking can significantly improve cracking performance of cement treated base. With a reduced cement content combined with microcracking, the amount of cracking in the base after two years has been reduced by approximately 50 percent as compared to the control.

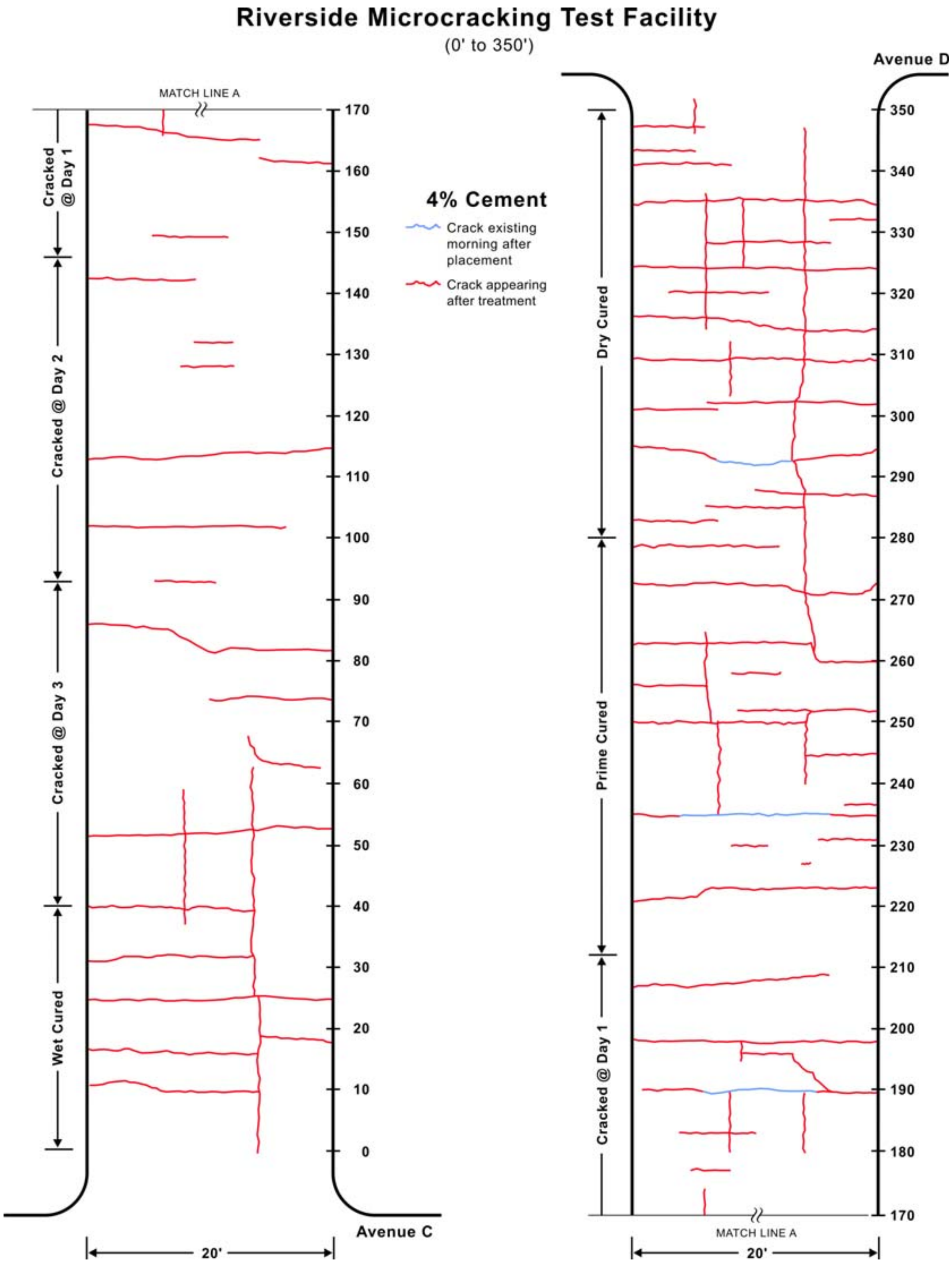


Figure 2.1. Crack Map of Riverside Test Sites with 4 Percent Cement.

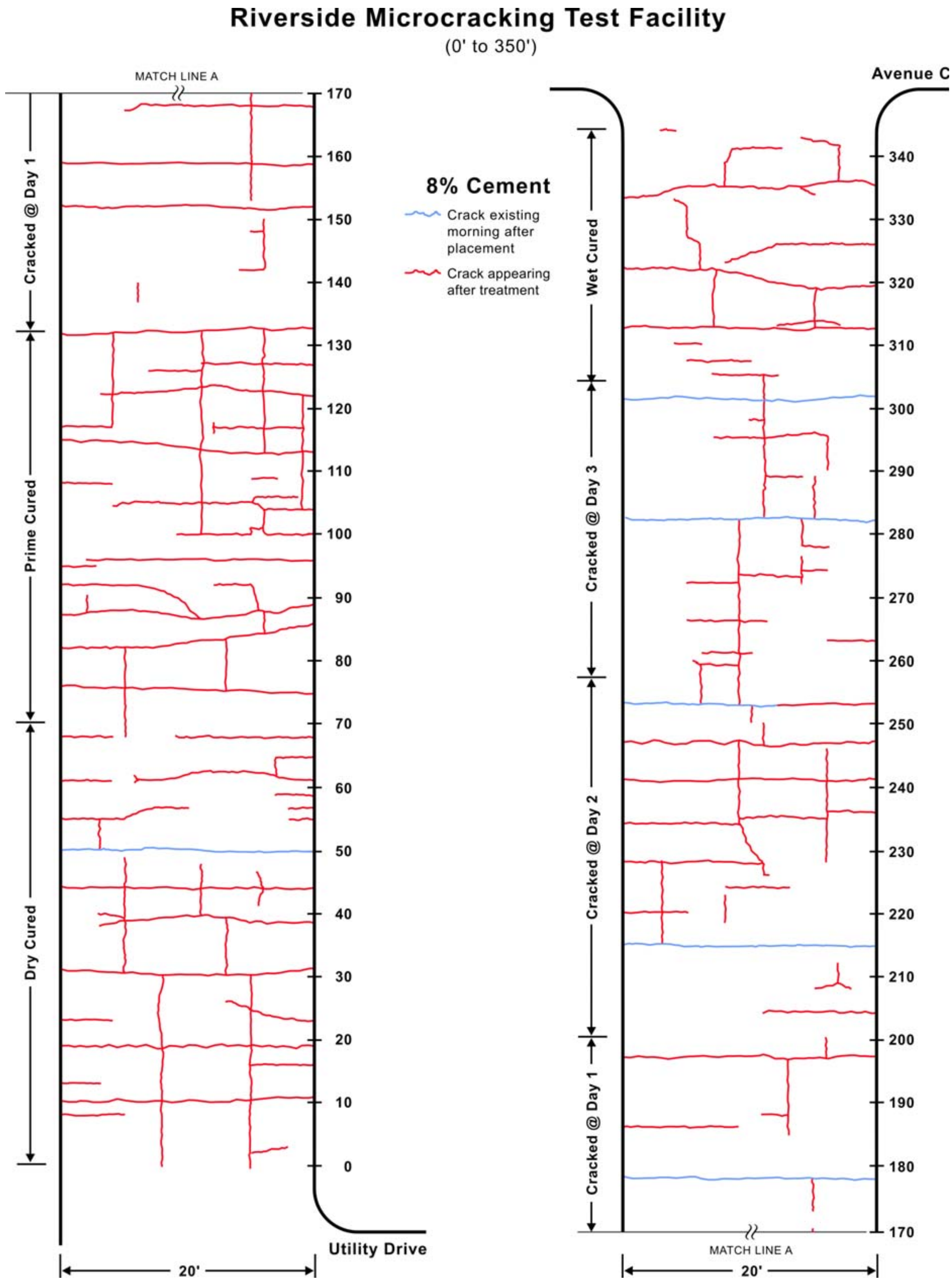


Figure 2.2. Crack Map of Riverside Test Sites with 8 Percent Cement.

Table 2.1. Cracking Statistics for Riverside Sites as of June 2005.

Cement Content (%)	Treatment	Crack Length per 100 Feet							Crack change as % of moist cure (preventable)
		9/9/2003	9/15/2003	1/28/2004	3/29/2004	6/28/2004	6/28/2005	6/28/2005*	
4	Dry Cure	9	43	57	57	89	416	N/A	32
	Prime Cure	18	29	51	59	78	306	288	-8
	Crack 1 Day	14	35	35	45	76	206	192	-39
	Crack 2 Day	0	0	17	19	34	98	98	-69
	Crack 3 Day	0	6	6	19	81	192	192	-39
	Moist Cure	0	8	50	50	50	315	315	N/A
8	Dry Cure	29	29	46	76	277	441	N/A	26
	Prime Cure	0	48	89	125	328	517	517	48
	Crack 1 Day	31	62	62	92	92	242	211	-40
	Crack 2 Day	58	58	58	73	105	369	311	-11
	Crack 3 Day	80	80	80	80	88	306	226	-35
	Moist Cure	0	0	15	33	70	350	350	N/A

*This column is only the crack length of preventable cracks
N/A: Not Applicable

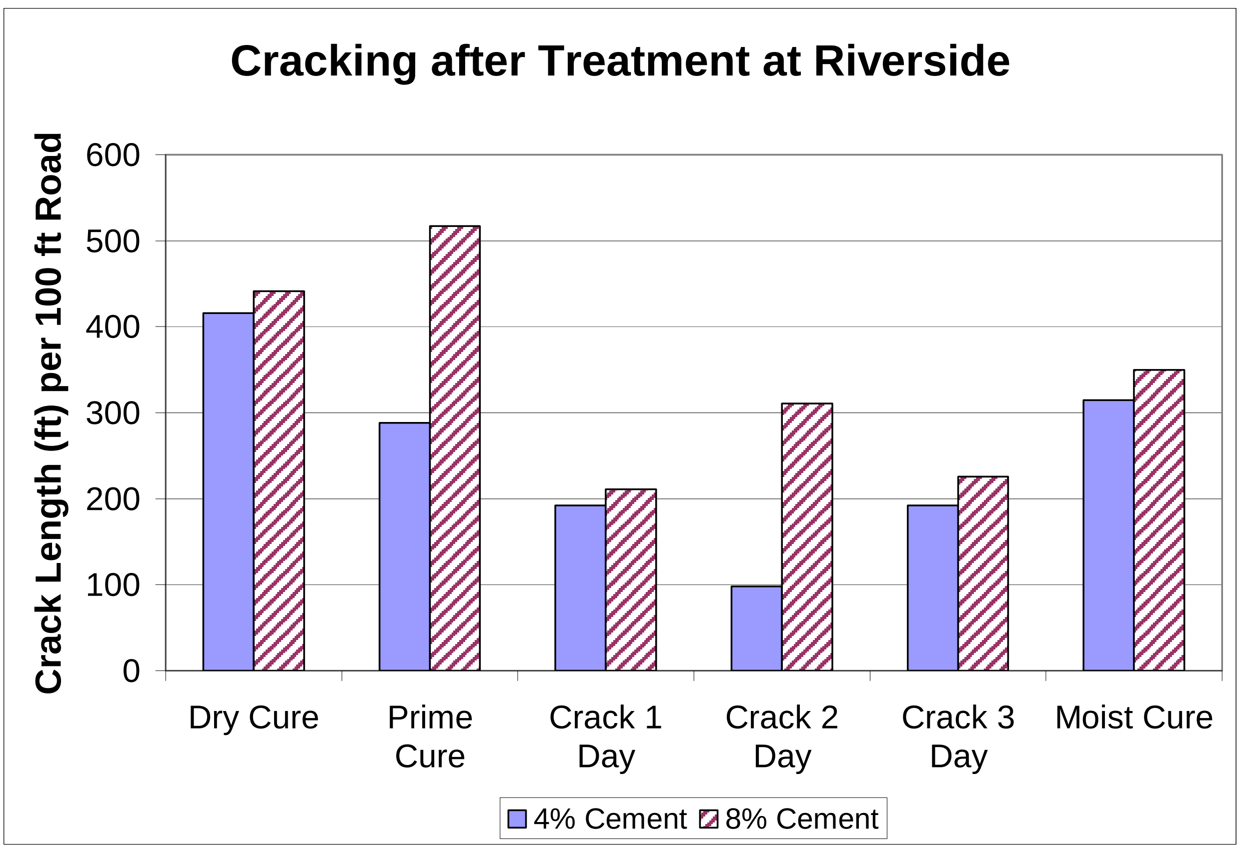
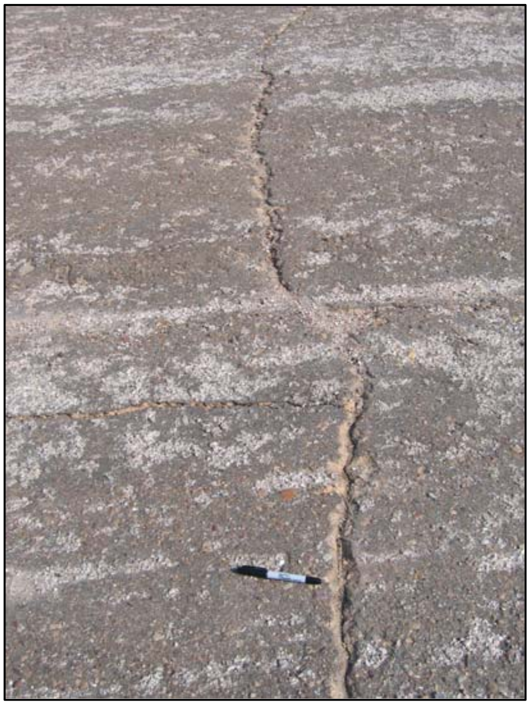


Figure 2.3. Crack Lengths after Treatment at Riverside Sites in June 2005.

Another previously noted benefit of microcracking is reduction in crack severity. As observed previously, sections microcracked continue to exhibit an overall reduction in crack severity, as shown in Figure 2.4.



Moist Cured

Microcracked

Figure 2.4. Reduction in Crack Severity by Microcracking.

MONITORING RESULTS FROM FWD

Tables 2.2 and 2.3 present the backcalculations from the survey conducted in June 2005. Figure 2.5 illustrates the average backcalculated modulus values for each of the Riverside sections at this time. The square marker denotes the average value, and the vertical lines represent the 95 percent confidence interval for the population mean. For a given treatment, statistical tests reveal when dry cured, microcracked after one day, or microcracked after two days, the sections with 8 percent cement currently have a higher mean modulus value than their counterpart sites treated with only 4 percent cement. The lower values at the sites with 4 percent cement are not a concern, however, since all of the backcalculated values are high, with all but one section greater than 1000 ksi.

The key question to answer from long-term FWD monitoring is whether microcracking reduces the in-service base modulus. Table 2.4 shows the results of an ANOVA test on the sites with 4 percent cement, which shows that no significant difference in mean modulus value exists among any of the sections treated with 4 percent cement. Table 2.5 shows the results of an ANOVA test on the sites with 8 percent cement, again showing no difference in mean modulus value among any of the treatments for that cement content. Microcracking did not alter the in-service modulus of the material.

Table 2.2. FWD Backcalculations at Riverside with 4 Percent Cement, June 2005.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.0)

		Thickness(in)	MODULI RANGE (psi) Minimum	Maximum	Poisson Ratio Values
District:					
County:					
Highway/Road:	Pavement:	0.50	200,000	200,000	H1: v = 0.3
	Base:	6.00	100,000	3,000,000	H2: v = 0.25
	Subbase:	0.00			H3: v = 0.00
	Subgrade:	153.42 (by DB)		15,000	H4: v = 0.4

Section	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERR/Sens	Dpth to Bedrock
Crack @ 1 Day	9,374	25.56	16.85	9.45	5.16	3.32	2.48	2.14	200	258.9	0	10.5	2.3	116.1
	9,378	21.65	14.15	7.65	4.51	3.11	2.28	1.82	200	327.2	0	12.3	5.3	183.6
	9,676	13.83	10.99	7.44	4.73	3.14	2.02	1.6	200	1420.4	0	12.1	1.87	143.6
	8,890	16.13	12.66	7.78	4.78	3.06	2.13	1.73	200	856.4	0	10.8	3.63	164.1
	9,346	10.64	8.1	5.5	3.66	2.55	1.78	1.42	200	2038	0	14.9	5.47	196.5
	9,418	12.95	9.67	6.48	4.22	2.8	1.95	1.6	200	1474.3	0	13.2	4.6	197.5
	8,262	14.34	11.18	7.23	4.59	3.26	2.3	1.76	200	1148.2	0	10.2	5.79	225.7
	9,446	12.46	10.01	7.07	4.59	3.21	2.22	1.69	200	1880.7	0	11.9	3.34	193.5
Crack @ 2 Days	8,786	34	23.35	12.56	6.62	4.41	2.8	2.07	200	162.9	0	7.5	3.83	106.2
	8,468	16.76	11.98	7.91	5.25	3.69	2.57	2	200	1009.6	0	9.4	7.36	207.4
	8,627	15.25	11.6	8.02	5.05	3.61	2.57	2	200	1235	0	9.7	5.71	300
	8,870	17.51	13.7	9.27	6.05	4.37	3.02	2.3	200	1149.9	0	8.4	5.29	203.9
	8,766	14.71	12.3	9.21	6.25	4.44	3.06	2.33	200	1852.8	0	8.1	1.92	197.9
	8,802	14.41	10.98	7.65	5.08	3.67	2.65	2.09	200	1525.6	0	10	6.26	261.8
	8,468	15.33	12.35	9.02	5.88	3.98	2.52	1.92	200	1330.3	0	8.6	1.28	141.7
	8,711	16.57	12.27	8.35	5.38	3.5	2.42	1.9	200	1016.9	0	9.6	3.81	181.7
Crack @ 3 Days	8,393	22.44	18.02	11.87	7.89	5.66	3.78	2.72	200	812.3	0	6.2	4.67	181.5
	9,160	14.48	12.33	8.38	5.12	3.32	2.25	1.88	200	1272.9	0	10.4	3.82	179.2
	9,827	13.92	10.45	7.02	4.46	3.11	2.22	1.74	200	1457.9	0	12.6	5.92	235.2
	8,886	14.38	11.82	7.94	5.19	3.54	2.26	1.85	200	1348	0	10.1	2.43	141.8
	8,925	18.04	14.55	9.28	5.64	3.56	2.56	1.95	200	829.8	0	9.2	3.95	156.7
	8,218	20.98	13.06	7.87	4.82	3.33	2.32	1.94	200	323.2	0	10.8	7.24	279
	8,782	13.04	9.7	6.73	4.28	2.94	2.06	1.57	200	1429.4	0	11.9	5.12	210.7
	9,144	14.36	10.76	7.2	4.62	3.06	2.09	1.72	200	1239.2	0	11.6	4.07	183.2
Dry Cure	8,675	19.55	15.73	8.49	4.63	2.94	2.06	1.53	200	431.4	0	10.5	5.14	114.9
	9,056	22.15	16.61	10.67	6.55	4.4	2.86	1.94	200	643.3	0	8.1	3.58	160.5
	9,589	18.87	15.24	11.63	8.35	5.89	3.1	2.57	200	1454.4	0	7.2	4.74	99.4
	9,311	21.26	17.27	12.43	8.64	6.03	3.33	2.51	200	1088.3	0	6.6	2.82	107.7
	8,262	18.74	13.67	8.6	4.82	3.35	2.27	1.78	200	561.9	0	9.6	4.72	133.9
	7,936	40.54	28.41	17.8	10.36	5.19	3.63	2.53	200	173	0	4.8	6.15	95.5
	8,369	22.3	18.91	11.23	5.96	3.71	2.54	1.86	200	444.2	0	7.8	5.97	107.8
	8,639	21.92	16.57	10.67	6.66	4.47	2.97	2.18	200	649.6	0	7.6	3.82	176.4
Moist Cure	8,897	12.45	10.62	8.21	5.96	4.19	3.22	2.59	200	2922.7	0	8.3	2.88	300
	8,584	21.15	17.1	12.98	9.54	7.11	5	3.63	200	1544.9	0	5.1	3.68	232.8
	7,932	20.52	18.33	14.83	10.52	7.61	4.99	3.99	200	1516.5	0	4.3	2.04	173.3
	8,762	12.08	10.15	7.61	5.01	3.51	2.41	1.91	200	2134.8	0	10.1	2.47	189.6
	8,131	19.76	13.82	8.32	5.05	3.33	2.26	1.78	200	463.9	0	9.6	4.7	189
	8,798	15.96	13.32	8.52	5.09	3.19	2.07	1.61	200	911.5	0	10.1	2.91	149.8
Prime Cure	9,656	16.63	14.63	11.56	7.59	4.76	2.41	1.81	200	1413.6	0	8.3	7.95	97.3
	9,394	31.51	20.81	10.45	5.33	3.32	2.21	1.76	200	148.7	0	9.6	6.64	91.2
	9,577	18.2	12.59	7.74	4.65	2.99	2.01	1.55	200	614.7	0	12.4	4.07	167.3
	9,601	22.22	13.07	8.43	5.37	3.4	2.04	1.54	200	377.3	0	12	6.54	121.1
	8,584	17.38	13.08	7.98	4.93	3.1	2.08	1.59	200	683.5	0	10.4	2.75	150.1
	8,770	22.26	17.61	11.19	7	4.51	2.69	2.11	200	620.5	0	7.5	1.61	126.4
	8,747	12.72	11.29	9.45	6.15	3.67	2.34	1.7	200	1961.6	0	9	6.78	121.2
	9,378	10.48	8.49	5.98	3.91	2.87	2.07	1.58	200	2456.3	0	13.5	5.02	246.6
Mean:		18.31	13.92	9.17	5.78	3.87	2.58	2	200	1100.4	0	9.6	4.39	159.9
Std. Dev:		5.94	3.93	2.39	1.61	1.1	0.68	0.5	0	640	0	2.3	1.68	51.1

Table 2.3. FWD Backcalculations at Riverside with 8 Percent Cement, June 2005.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.0)

District:
County:
Highway/Road:

	Thickness(in)	MODULI RANGE (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	0.50	200,000	200,000	H1: v = 0.30
Base:	6.00	150,000	5,000,000	H2: v = 0.25
Subbase:	0.00			H3: v = 0.00
Subgrade:	226.14 (by DB)	15,000		H4: v = 0.4

Section	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERR/Sens	Dpth to Bedrock
Crack @ 1 Day	8,854	11.56	9.19	6.61	4.48	3.31	2.46	1.83	200	1963.2	0	13	3.91	253.2
	9,219	11.06	10.59	7.89	5.4	3.98	2.74	2.07	200	2743.6	0	11	3.67	189.6
	10,014	10.21	7.93	5.67	4.05	3.01	2.26	1.87	200	2767	0	16.4	5.26	300
	9,648	9.93	8.7	6.46	4.29	3.21	2.51	1.86	200	3046.7	0	14.1	4.57	300
	8,544	14	11.66	9.91	6.86	4.83	3.19	2.39	200	2073.2	0	8.4	3.13	163.3
	8,504	15.44	13.1	10.09	7.5	5.53	4.01	2.99	200	2059.7	0	7.4	1.25	269.5
	9,096	15.78	13.81	10.4	7.6	5.34	3.74	2.74	200	1862.1	0	8.1	0.87	213.8
	9,227	10.08	8.34	6.09	4.23	3.1	2.34	1.89	200	2699	0	14.3	3.11	300
Crack @ 2 Days	9,291	9.11	7.19	5.32	3.82	2.89	2.16	1.75	200	3306.1	0	15.8	4.8	300
	8,945	9.81	7.19	5.09	3.38	2.61	2.02	1.72	200	2127.9	0	17.1	7.61	300
	9,875	10.69	8.18	5.11	3.67	2.76	2.11	1.74	200	1955.6	0	17.9	7.48	300
	8,691	10.5	7.87	5.28	3.68	2.67	2.06	1.65	200	1801.5	0	15.8	6.16	300
	9,275	11.21	9.43	6.67	4.46	3.22	2.41	1.85	200	2086.1	0	13.7	3.19	300
	9,493	12.24	8.94	6.21	4.09	2.77	2.15	1.73	200	1491.4	0	15.7	4.02	230.1
	8,703	10.03	8.27	6.04	4.14	3	2.22	1.8	200	2410.2	0	13.9	2.54	300
	9,013	11.02	8.79	5.76	3.63	2.67	2.03	1.71	200	1564.9	0	15.9	4.65	300
Crack @ 3 Days	9,334	11.8	8.36	5.24	3.61	2.55	1.84	1.5	200	1258.5	0	17.7	5.98	239.6
	9,926	7.59	6.44	4.83	3.32	2.46	1.85	1.52	200	4252.2	0	19.2	3.16	300
	8,588	10.46	7.61	5.21	3.52	2.61	1.98	1.61	200	1724.6	0	16.1	6.73	300
	8,596	11.7	9.56	6.87	4.83	3.46	2.24	1.75	200	1861	0	12.2	1.08	144.1
	9,410	12.2	9.07	5.68	3.41	2.59	1.92	1.59	200	1113.1	0	17.4	5.87	206
	9,442	9.8	7.93	5.4	3.56	2.62	1.95	1.54	200	2148.4	0	17.3	4.15	300
	8,536	16.2	11.7	7.29	4.59	2.97	1.92	1.5	200	610.1	0	12.9	1.35	148.1
	9,021	21.43	13.57	6.98	4.22	2.73	1.94	1.61	200	241	0	13.8	2	172.2
Dry Cure	8,131	16.97	14.74	8.83	6.3	4.58	3.26	2.52	200	949.6	0	8.7	5.49	238.5
	8,317	12.29	10.43	8.37	6.72	5.08	3.76	1.94	200	3513.7	0	7.7	1.55	108.9
	8,258	20.01	15.57	11.94	8.6	6.2	4.18	2.85	200	1176.3	0	6.6	1.93	183.1
	8,449	12.18	10.66	7.84	5.57	4.05	2.94	2.4	200	2198.4	0	9.9	2.04	268.3
	8,401	13.13	10.95	8.3	5.83	4.11	2.67	2.27	200	1786.5	0	9.9	1.3	149.3
	8,218	14.03	12.67	10.01	7.28	5.45	3.9	2.89	200	2382.4	0	7.1	1.4	251.6
	8,611	17	13.7	10.64	7.22	4.54	3.23	2.44	200	1205.3	0	8.5	3.06	152.8
	8,413	20.14	16.48	11.46	7.58	4.92	3.15	2.29	200	760.3	0	7.9	2.91	152.5
Moist Cure	8,564	11.32	9.21	6.46	4.51	3.28	2.33	1.8	200	1916.2	0	12.7	2.88	222.8
	8,643	12.7	10.52	7.86	5.31	3.76	2.61	1.97	200	1784.3	0	11	1.27	201.2
	8,731	8.92	7.51	5.69	4.02	2.89	2.09	1.63	200	3132.8	0	14.4	1.68	246.3
	8,655	13.05	10.09	6.53	3.86	2.65	1.93	1.54	200	945.9	0	14.6	2.8	185.4
	8,373	13.35	10.69	6.59	4.15	2.72	1.92	1.53	200	886.1	0	13.6	2.23	186.2
	9,096	16.07	12.17	8.26	5.38	3.51	2.3	1.65	200	916	0	11.9	1.21	155.5
Prime Cure	8,421	15.02	12.94	10.16	7.25	4.96	3.4	2.54	200	1755.1	0	8	2.08	193.1
	8,532	13.5	12.1	8.06	5.13	3.43	2.57	2.16	200	1252.1	0	11.1	4.57	223.1
	8,345	15.53	12.2	8.21	5.46	3.72	2.68	2.2	200	1012.4	0	10.4	1.68	261.4
	8,143	20.42	14.25	8.81	5.42	3.74	2.74	2.14	200	430.3	0	10.1	3.54	300
	8,361	14.63	11.66	7.94	5.23	3.73	2.67	2.13	200	1149.1	0	10.7	2.58	250.8
	8,405	16.61	12.89	9.02	6.14	4.23	3	2.37	200	1052.5	0	9.4	1.98	237.5
	8,234	18.62	15.64	9.78	6.07	4.32	2.97	2.37	200	690.9	0	8.9	3.23	300
	8,703	12.68	11.42	8.25	5.76	4.2	3.02	2.4	200	2081.8	0	9.9	2.55	252.4
Mean:		13.3	10.69	7.5	5.11	3.63	2.6	2.01	200	1785.8	0	12.3	3.27	232.6

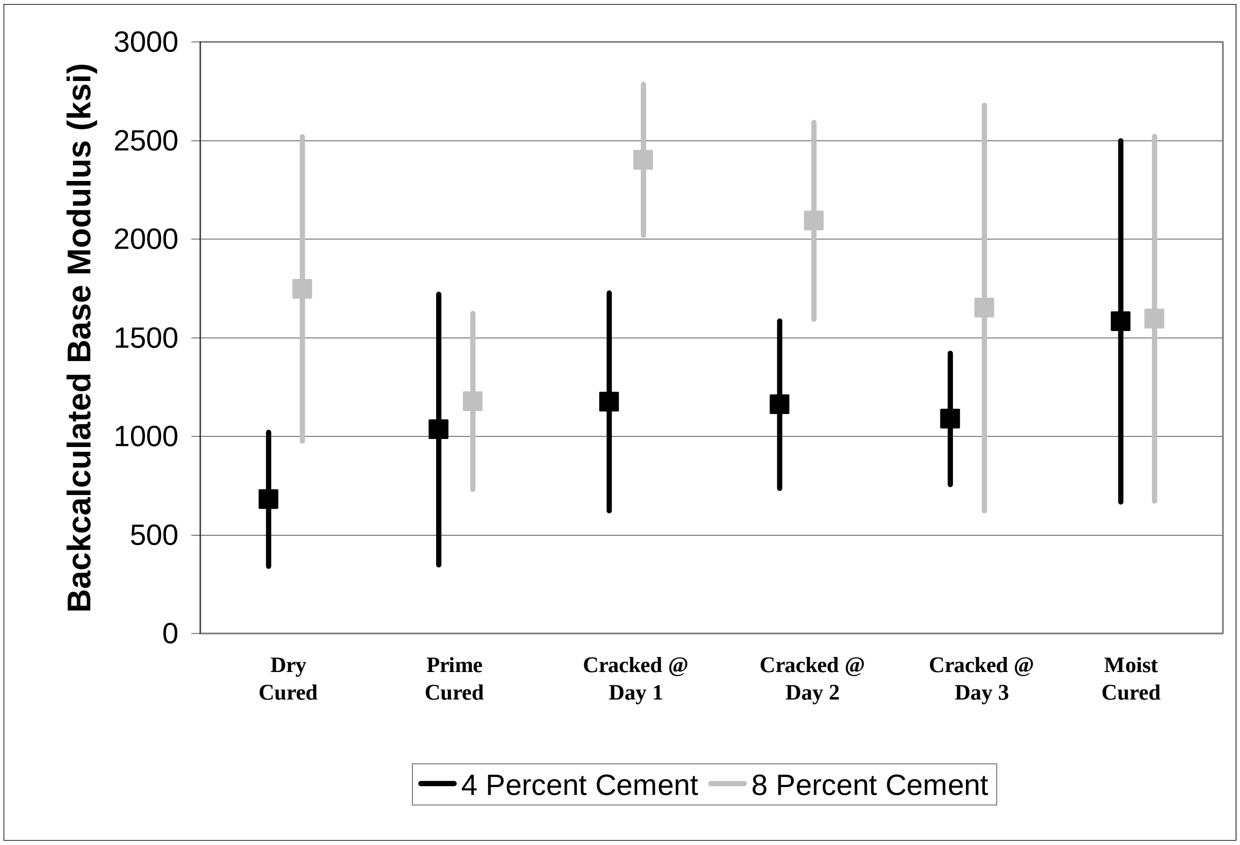


Figure 2.5 Modulus Values of Riverside Test Sites in June 2005.

Table 2.4. ANOVA Result on FWD Data from 4 Percent Cement, June 2005.

Groups	*Count*	*Sum*	*Average*	*Variance*
Dry Cure	8	5445	680.625	165210.8
Prime Cure	8	8277	1034.625	673142.3
1 Day	8	9403	1175.375	436182.8
2 Day	8	9285	1160.625	240931.1
3 Day	8	8712	1089	157966.3
Wet Cure	6	9495	1582.5	761727.5

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2913848	5	582769.5	1.501725	0.211007	2.449468
Within Groups	15522671	40	388066.8			
Total	18436519	45				

Table 2.5. ANOVA Result on FWD Data from 8 Percent Cement, June 2005.

Groups	*Count*	*Sum*	*Average*	*Variance*
Dry Cure	8	13971	1746.375	851373.7
Prime Cure	8	9423	1177.875	285223.8
1 Day	8	19215	2401.875	209135.6
2 Day	8	16743	2092.875	331261
3 Day	8	13207	1650.875	1511045
Wet Cure	6	9581	1596.833	777821.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7119652	5	1423930	2.173493	0.076319	2.449468
Within Groups	26205380	40	655134.5			
Total	33325032	45				

CONCLUSIONS FROM TEST SITE

At the test sites constructed at Riverside Campus in September 2003, monitoring over the past two years substantiated the positive effects from microcracking. Microcracking after two days curing yielded the best performance with the sections constructed with 4 percent cement. On average, with current mix design recommendations, microcracking reduced the amount of cracking by approximately 50 percent as compared to the control (moist cured). Microcracking also reduces cracking problems at higher cement contents; however, microcracking alone is not sufficient to optimize crack performance. By combining microcracking with current mixture design recommendations (300 psi UCS after seven days curing and pass moisture susceptibility criteria), significant improvements in crack performance were realized. In addition to reduced crack length, microcracking reduces crack severity (width), and FWD observations indicate microcracking does not have a detrimental impact on the long-term base modulus.

CHAPTER 3

IH 45 FRONTAGE ROAD TEST SITES

SUMMARY

In December 2004 and May 2005, TxDOT constructed cement-treated base sections in TxDOT's Huntsville Area Office. The sections were frontage road rehabilitation projects and, with the exception of a 200 foot control section, all sections were microcracked. The contractor did not have any problems microcracking the sections; however, in December, three days' curing was not sufficient time before microcracking. Due to the lower daily temperatures the sections were cured for four days prior to initiation of microcracking. In December, the average daily temperatures were less than 60 °F. These sections highlighted the need for longer curing times before initiation of microcracking when construction is performed in cooler months.

LABORATORY DESIGN OF CEMENT-TREATED BASE

Before construction, TTI performed a laboratory cement content design series on the Texas Crushed Stone limestone flex base used at the project site. Design tests included seven day unconfined compressive strength (Test Method Tex-120-E) and the Tube Suction Test. In the Tube Suction Test, 4 inch diameter by 4.58 inch tall test specimens were used, and the amount of aggregate retained on the 3/4 inch sieve was added proportionally to the 3/8 and plus #4 fractions.

TxDOT provided the optimal moisture content of 7.1 percent and maximum dry density of 133.5 pcf. The TTI laboratory recombined test specimens according to the gradation shown in Table 3.1 then tested specimens in duplicate in the design tests. Table 3.2 shows the results from the mix design tests. Based upon a mix design criteria of at least 300 psi after seven days curing and a final dielectric value less than 10 after the Tube Suction Test, the recommended design cement content was 4 percent. While consideration was given to recommending 3.5 percent due to the high seven-day strengths, the decision to proceed with 4 percent was made based upon the Tube Suction Test. As Figure 3.1 shows, after the Tube Suction Test the height of capillary rise in specimens treated with 4 percent still was quite near the surface of the specimen. The high strength of this material at the cement content required to pass the moisture susceptibility test makes the material a good candidate for microcracking in the field.

Table 3.1 Recombining Percentages for Texas Crushed Stone Flex Base.

Sieve Size	Individual Percent Retained
1 1/4	4.3
7/8	10.4
3/4	6.2
3/8	19.8
#4	14.1
Pan	45.2

Table 3.2. Results from Mix Design Test with Texas Crushed Stone Flex Base.

Cement Content (%)	7-Day UCS (psi)	Dielectric after Tube Suction Test
2	501	12.0
3	792	11.9
4	1137	7.3
5	1485	7.6
6	1573	6.3
8	*	6.3

***** 8 percent cement strength specimens not constructed due to excessively high strengths.

Figure 3.1. Texas Crushed Stone Cement-Treated Base after Tube Suction Test.
(l to r: 2, 3, 4, 5, 6, and 8 percent cement)

DESCRIPTION OF TEST SECTIONS

The construction project consists of southbound and northbound sections of the IH 45 frontage roads in Huntsville, TX. The structure consists of 10 inches of lime-treated subgrade, 12 inches of pug mill-mixed cement-treated base, and 5 inches of hot-mix asphalt. First, the contractor performed the base work on the outside lanes in December 2004. After surfacing, traffic was routed onto the completed outside lanes for reconstruction of the inside lanes. The cement-treated base on the inside lanes was placed in May 2005. The southbound section begins north of the intersection of SH 30 and IH 45 at GPS coordinates N 30° 43.375' W 95° 34.774' (in front of the Holliday Unit prison facility). The end of the microcracked section in the southbound direction is at N 30° 43.390' W 95° 34.426'. A control section not microcracked, 200 feet long, continues toward SH 30 beyond the location where microcracking was performed. Figure 3.2 shows the southbound section.

The entire section of the northbound frontage road was microcracked. This section is south of where SH 30 meets IH 45 and begins at N 30° 42.530' W 95° 33.792'. The end of the project is at N 30° 42.647' W 95° 33.861'. Figure 3.3 shows the northbound section.

Figure 3.2. Looking South on the SB IH 45 Frontage Road Project.

Figure 3.3. Looking North from the Start of the NB IH 45 Frontage Road Project.

SCHEDULE OF ACTIVITIES

Table 3.3 summarizes the activities on this project that TTI participated in to help administer and monitor the microcracking procedure.

Table 3.3. Schedule of Activities on IH 45 Frontage Road Project.

Date	Activities
12-02-2004	• Contractor starting placing CTB in SB outside lane • Placed base from the northern project limit to STA 1088
12-03-2004	• Contractor placed CTB from STA 1088 to STA 1099+50 • TTI performed FWD and PFWD from STA 1079 to 1086+50 • Based on data collected, did not microcrack any sections
12-06-2004	• Contractor finished placing CTB on SB outside lane (STA 1099+50 to 1108+50) • TTI collected PFWD data from STA 1079 to 1098+50 • Based on PFWD, only microcracked from the northern project limit to STA 1088. Performed microcracking with 3 passes of an Ingersol Rand DD-125 roller • After microcracking passes, TTI collected PFWD data from STA 1079 to 1088
12-07-2004	• Contractor placed all CTB on NB outside lane • TTI collected PFWD data from STA 1088+50 to STA 1099 on the SB inside lane • Contractor microcracked on the SB project from STA 1089 to 1099+50 with 3.5 passes with a Dynapac CA 252 roller. The contractor did not microcrack from STA 1088 to 1089 because traffic had to go through those stations for access to Veterans Memorial Parkway. • After microcracking, TTI collected PFWD data from STA 1089 to 1099+50
12-10-2004	• TTI collected PFWD data on the SB project from STA 1100 to 1106. • Contractor microcracked on the SB project from STA 1099+50 to 1106+50 with 3.5 passes of the Dynapac CA 252 roller. A control section (STA 1106+50 to 1108+50) was not microcracked. • After microcracking, TTI collected PFWD data from STA 1100 to 1106. • The contractor microcracked the entire NB outside lane project by applying 3.5 passes of the Dynapac CA 252 roller. TTI monitored the process with the PFWD.
05-02-2005	• Contractor placed CTB in the SB inside lane from STA 1097+80 to 1100
05-03-2005	• Contractor finished placing CTB in the SB inside lane from STA 1100 to 1108+50.
05-05-2005	• TTI performed FWD and PFWD testing on the SB inside lanes from STA 1098 to 1106. • Contractor microcracked the SB inside lane from STA 1097+80 to 1106+50 with 3.5 passes of the Dynapac CA 252 roller.

RESULTS FROM NON-DESTRUCTIVE TEST (NDT) TESTING

Outside Lane Results

The research team conducted the first FWD survey from STA 1079 to STA 1086+50 on December 3, 2004, after one day curing. The average base modulus at this time was only 90 ksi, so no microcracking was performed on that day. During the rest of the base construction in December, the FWD was not available, so the research team used the PFWD to monitor the base stiffness for microcracking. Based upon data in the field and prior recommendations for using the PFWD to control microcracking (*1*), only the sections with four days curing time were microcracked on December 6. Table 3.4 shows these results, which indicated the average base modulus was reduced by 38 percent from the PFWD calculations. Figure 3.4 shows microcracking in progress in this section.

Table 3.4. NDT Results from STA 1079 to 1088 Microcracked after Four Days Curing.

Station	E1 before Microcracking (ksi)*	E1 after Microcracking (ksi)*
1079	125	193
1080	447	139
1081	332	148
1082	340	104
1083	328	71
1084	262	286
1085	382	256
1086	256	179
1087	242	154
1088	343	363
Average	306	189

*From PFWD center sensor calculation

Figure 3.4. Microcracking IH 45 SB OL on December 6, 2004.

On December 7, 2004, the sections from STA 1088 to 1099+50 had cured for four days and were microcracked. Figure 3.5 shows the microcracking in progress, and Table 3.5 shows the PFWD data used to control the process.

Figure 3.5. Microcracking IH 45 SB OL on December 7, 2005.

Table 3.5. PFWD Results from Locations Microcracked December 7, 2004.

Station	E1 before Microcracking (ksi)*	E1 after Microcracking (ksi)*
1089	221	126
1090	205	140
1091+82	215	196
1093	111	238
1094	328	127
1095	320	236
1096	69	42
1096+50	282	192
1098	153	110
1099	134	151
Average	204	156

*From PFWD center sensor calculation

On December 10, 2004, the contractor microcracked from STA 1099+50 to STA 1106+50 on the southbound project site at a curing age of four days and also microcracked the entire northbound outside lane, which was at a curing age of three days. The roller used was the Dynapac CA 252 shown in Figure 3.5. Tables 3.6 and 3.7 show the PFWD data from the southbound and northbound sites, respectively.

Table 3.6. PFWD Results from SB OL Locations Microcracked December 10, 2004.

Station	E1 before Microcracking (ksi)*	E1 after Microcracking (ksi)*
1100	182	101
1101	431	187
1102	446	209
1103	502	323
1104	179	432
1105	377	292
1106	388	169
Average	358	245

*From PFWD center sensor calculation

Table 3.7. PFWD Results from NB OL Locations Microcracked December 10, 2004.

Test Location	E1 before Microcracking (ksi)*	E1 after Microcracking (ksi)*
1	222	167
2	107	51
3	175	118
4	282	279
5	98	33
6	155	133
Average	173	130

*From PFWD center sensor calculation

Inside Lane Results

On May 2, 2005, the contractor placed base from STA 1097+80 to 1100, then finished placing the southbound inside lane (IL) from STA 1100 to 1108+50 on May 3, 2005. On May 5, TTI monitored microcracking from STA 1097+80 to 1106+50 (the last 200 feet of the project were not microcracked to serve as a control section). The contractor applied 3.5 passes with the Dynapac CA 252 roller to microcrack the section. Tables 3.8 and 3.9 show the FWD data used to control the process. Microcracking reduced the average base modulus from 476 to 204 ksi, representing a reduction of 57 percent.

Table 3.8. FWD before Microcracking on SH 45 SB IL, May 2005.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.0)

		Thickness(in)	MODULI RANGE (psi) Minimum	Maximum	Poisson Ratio Values
District:					
County:					
Highway/Road:	Pavement:	0.50	200,000	200,000	H1: v = 0.3
	Base:	12.00	200,000	1,500,000	H2: v = 0.25
	Subbase:	10.00	10,000	100,000	H3: v = 0.35
	Subgrade:	262.37 (by DB)	15,000		H4: v = 0.4

Section	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERR/Sens	Dpth to Bedrock
1098	10,046	9.39	5.78	4.06	3.1	2.41	1.84	1.5	200	298.3	95.7	16.7	5.34	300
1099	9,207	6.95	5.08	3.58	2.74	2.11	1.62	1.32	200	486.7	67.9	19.4	2.5	300
1100	9,180	9.56	5.9	4.22	3.1	2.33	1.72	1.4	200	251.4	80.4	15.6	3.22	273.9
1101	10,200	5.21	4.13	3.13	2.4	1.83	1.41	1.11	200	1329.2	13.3	31.3	1.33	300
1102	9,164	7.44	4.83	3.29	2.43	1.81	1.36	1.09	200	359.1	68.1	21.4	3.19	300
1103	9,545	6.33	4.9	3.43	2.48	1.85	1.4	1.13	200	631.9	36.7	24.3	3.35	300
1104	8,969	9.91	6.76	4	2.62	1.83	1.29	1.03	200	273.4	11.1	24.6	3.8	203
1105	9,144	6.35	3.86	2.38	1.65	1.19	0.85	0.67	200	362.6	55.5	31.7	3.59	210.7
1106	9,330	7.63	4.39	2.54	1.85	1.31	0.99	0.83	200	289.5	47.9	28.5	5.9	300
Mean:		7.64	5.07	3.4	2.49	1.85	1.39	1.12	200	475.8	52.9	23.7	3.58	284.9
Std. Dev:		1.65	0.93	0.65	0.49	0.41	0.32	0.26	0	342.2	28.8	6	1.37	44.9
Var Coeff (%):		21.56	18.38	19.06	19.87	22.11	23.19	23.59	0	71.9	54.4	25.1	38.33	16.6

Table 3.9. FWD after Microcracking on SH 45 SB IL, May 2005.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.0)

		Thickness(in)	MODULI RANGE (psi) Minimum	Maximum	Poisson Ratio Values
District:					
County:					
Highway/Road:	Pavement:	0.50	200,000	200,000	H1: v = 0.3
	Base:	12.00	75,000	1,500,000	H2: v = 0.25
	Subbase:	10.00	5,000	100,000	H3: v = 0.35
	Subgrade: 241.02 (by DB)		15,000		H4: v = 0.4

Section	Load (lbs)	Measured Deflection R1	R2	(mils): R3	R4	R5	R6	R7	Calculated SURF(E1)	Moduli BASE(E2)	values SUBB(E3)	(ksi): SUBG(E4)	Absolute ERR/Sens	Dpth to Bedrock
1098	9,450	14.22	7.94	4.8	3.45	2.54	1.92	1.6	200	152.5	24.1	16.1	6.96	300
1099	9,156	13.33	7.76	4.47	3.35	2.38	2.09	1.55	200	168.4	20.3	16.7	8.07	300
1100	9,319	13.87	8.32	5.45	3.7	2.61	1.85	1.46	200	163.7	22.8	15.1	2.09	214.3
1101	9,609	6.92	4.85	3.71	2.79	2.13	1.51	1.22	200	523.9	65.8	20.7	0.87	203.1
1102	9,235	9.27	6.2	3.73	2.6	1.91	1.41	1.09	200	273.9	28.8	21.3	4.86	274.1
1103	8,941	11.74	6.13	3.71	2.55	1.89	1.39	1.13	200	163.3	29.8	20.2	7.74	267.6
1104	9,104	13.24	8.83	4.37	2.69	1.86	1.3	1.04	200	166.5	9.2	23.8	6.85	256.5
1105	8,925	15.86	7.28	2.89	1.65	1.11	0.83	0.68	200	118.9	8.2	39.6	14.21	76
1106	9,112	13.23	6.09	2.93	1.83	1.33	0.97	0.82	200	107.5	30	26.5	10.12	285.6
Mean:		12.41	7.04	4.01	2.73	1.97	1.47	1.18	200	204.3	26.6	22.2	6.86	263.5
Std. Dev:		2.74	1.3	0.85	0.7	0.51	0.42	0.32	0	128.6	16.8	7.5	4.02	155.5
Var Coeff (%):		22.06	18.41	21.1	25.45	25.96	28.69	26.93	0	63	63.3	33.7	58.62	60.3

SURVEY RESULTS FROM AUGUST 2005

In August 2005, TTI returned to the project site to look for evidence of any shrinkage cracking. Additionally, FWD was collected. TTI focused on the southbound outside lane, because this section was the oldest and also includes the control section. Figure 3.6 shows part of the microcracked section, and Figure 3.7 shows the control section. No signs of transverse cracking were seen. This was expected since the section was only eight months old and had 5 inches of HMA surfacing. Table 3.10 shows summary FWD results from 48 drops in the microcracked sections and 13 drops in the control section. Given the variability in observed values, no difference in modulus exists among the microcracked or control sections. Additionally, the backcalculated base moduli values are substantially high. Factors that could help explain these high values are incorrect layer thicknesses or the possibility of higher cement content in the field mixture. Efforts to verify the base thickness with ground-penetrating radar (GPR) were unsuccessful because no reflection was observable from the bottom of the base. Information on depth checks during construction was not available in time for this report. No field samples were collected during construction for strength tests, so it is unknown how the cement content of the field mix compared to the specified target.

Figure 3.6. Looking South from Veterans Memorial Parkway in Microcracked Section, August 2005.

Figure 3.7. Looking South in Control Section on IH 45 Frontage Road, August 2005.

Table 3.10. Summary FWD Results from August 2005 on IH 45 SB OL.

		SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Dpth to Bedrock
Control	Mean:	295.4	5868.2	25	29.1	1.69	163
	St Dev:	54.4	3056.2	11.7	3.9	0.81	61.1
	Var Coeff (%):	18.4	52.1	46.7	13.4	48.21	37.5
Microcracked	Mean:	379.5	6174.9	23.5	30.9	1.02	300
	St Dev:	96	2316.9	10.7	9	0.53	90.1
	Var Coeff (%):	25.3	37.5	45.6	29	51.91	30

CONCLUSIONS

The most significant observation to date from these test sites is that, when construction was performed in cooler weather conditions, the base had not cured enough for microcracking after three days curing. In TxDOT's Flexible Pavement Design System (FPS), cement-treated bases are normally assigned a modulus value of 200 ksi. The research team believes the modulus should at least be in the vicinity of that value before microcracking. At these test sites, the average daily temperature in December was less than 60 °F, and the base was cured for four days prior to microcracking. Based upon observations at these test sites, the recommendations for microcracking were modified to incorporate longer curing times before microcracking when performing construction in cooler climate conditions.

CHAPTER 4

THE ECONOMICS OF MICROCRACKING

SUMMARY

In this project the research team desired to investigate the economics of microcracking. Based upon field performance at the microcracking test site, microcracking reduces cracking in the base by approximately 40 to 70 percent. Essentially this means that microcracking saves money by reducing the amount of crack sealing on the section in the future. Based on current costs of rolling and crack sealing, and the reduction in cracking by microcracking, the procedure provides a rate of return of approximately 47 percent. Based on the current statewide usage of CTB, even if implemented on only 25 percent of projects, microcracking could provide a net present value (NPV) cost savings to TxDOT of approximately $1.5 million per year. Given the range of observed effectiveness of microcracking, full implementation could save between $3.3 and $8.6 million in yearly NPV costs.

ECONOMICS OF MICROCRACKING

Field performance of a properly designed CTB at the microcracking test site indicated microcracking reduces the amount of cracking in the base by 50 percent on average. This improvement in performance means microcracking could cut in half the amount of crack sealing necessary in the future when preparatory work takes place for applying a seal coat. TxDOT typically applies a seal coat after 7 years, so the future benefits of microcracking must outweigh the cost of applying the procedure. The following two examples illustrate the economic advantage from microcracking. First, an example of microcracking a typical 1000 foot section of roadway is presented. Next, the potential savings for the entire state is estimated based upon current statewide usage of CTB. In both examples, the following assumptions were made:

- Microcracking a pavement lane requires three passes (with a pass defined as down and back), at three different transverse offsets. Therefore, the distance traveled by the roller is 18 times the length of the section.
- The roller applying microcracking travels at 3 mph and is paid for at $50 per hour.
- Microcracking reduces the amount of crack seal necessary in the future by 50 percent.
- Crack sealing takes place at year 7 and costs $0.91 per linear foot (cost based on the 12 month moving average TxDOT bid prices for Item 712 paid by the linear foot) (*3*).
- The amount of cracking in non-microcracked sections at the time of sealing is 1.4 ft per yd^2 pavement. This value is equivalent to the current amount of cracking in the control section at the Riverside Campus test facility.
- Future costs are discounted at a 4 percent real discount rate.

Economics of Microcracking a 1000 Foot Section

With the given assumptions, Figure 4.1 illustrates the estimation of savings by microcracking a 1000 foot section. Microcracking would cost $57 during construction and save $849 in crack seal costs at year 7. With a discount rate of 4 percent, this translates to a net present value savings of $589 for the 1,000 foot section, or a rate of return of approximately 47 percent.

Microcracking Data

User Inputs					*Analysis Outputs*		
Section Length (ft)	Number of Roller Passes	Number of Roller Transverse Offsets	Roller Speed (mph)	Unit Cost of Rolling ($/hr)	Roller hours	Miles Traveled by Roller	Cost of Rolling
1000	3	3	3	50	1.1	3.4	57

Field Cracking Data

User Inputs			*Analysis Outputs*		
Section Width (ft)	Cracking in Control (ft/yd2)	Reduction by Microcracking (%)	Cracking in Microcracked (ft/yd2)	Total Cracking in Control (ft)	Cracking in Microcracked (ft)
12	1.4	50.00%	0.7	1867	933

Economics Data

User Inputs			*Analysis Outputs*					***Summary Output***	
Crack Seal ($/ft)	Time to Sealing (years)	Discount Rate	Cost of Sealing Control	Cost of Sealing Microcracked	Savings from Microcracking at T=7 years	NPV of Control Costs	NPV of Microcracking Costs	NPV Savings by Microcracking	Rate of Return for Microcracking
0.91	7	4.0%	1699	849	849	1291	702	589	47.2%

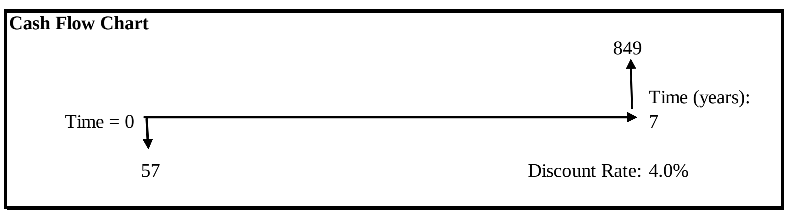


Figure 4.1. Economics of Microcracking a 1000 Foot Pavement Lane.

Of further interest is the sensitivity of the economics to changes in analysis assumptions. Figure 4.2 illustrates the rates of return for varying percentage reductions in cracking while maintaining as constant all other assumptions. Given the extremely low initial cost of microcracking, the procedure needs to only provide around a 7 to 10 percent reduction in cracking to easily exceed any reasonable required minimum rate of return. Data collected under this project show, at worst, microcracking reduced cracking by 11 percent. With properly designed sections the reduction in cracking ranged from approximately 40 to 70 percent.

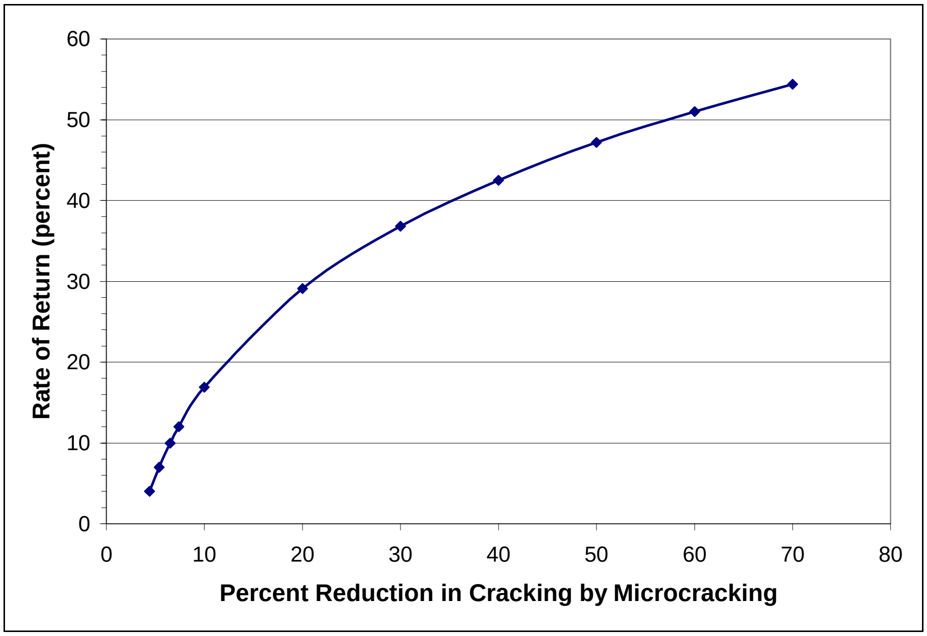


Figure 4.2. Rate of Return for Varying Percentage Reductions in Cracking by Microcracking.

Another important parameter that influences the economics of microcracking is the rising costs of asphaltic materials, including crack sealing. Figure 4.3 illustrates the influence of the NPV of microcracking as the cost of crack sealing changes. Clearly, the higher the cost of sealing cracks, the higher are the economic benefits from microcracking.

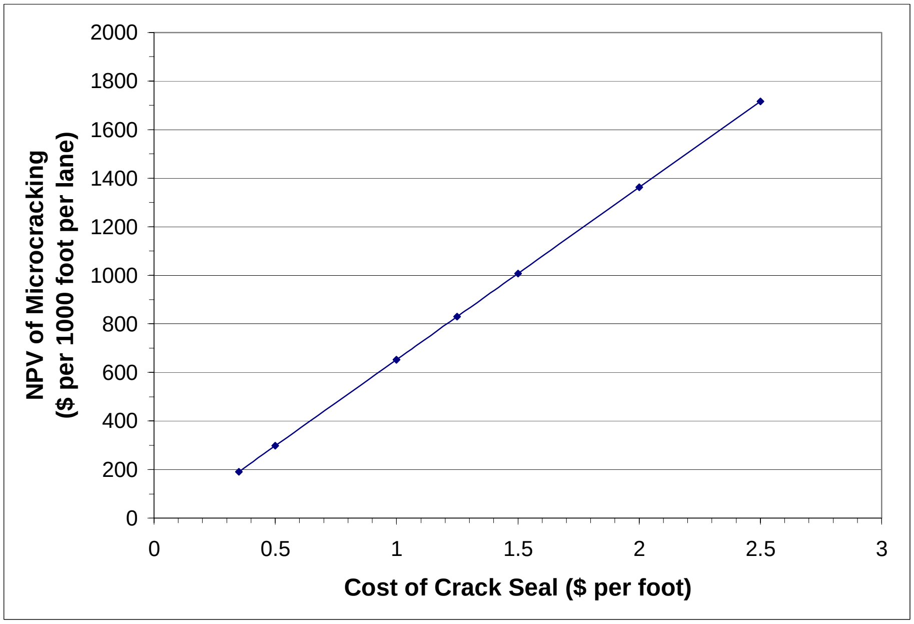


Figure 4.3. NPV of Microcracking versus Cost of Crack Sealing.

Economics of Statewide Microcracking

According to TxDOT records, nearly 13.5 million square yards of CTB were placed over the last 12 months *(3)*. This usage equates to approximately 10,102 sections of the previously described typical 1000 foot section. For each 1,000 foot section, the estimated NPV of microcracking was $589. Therefore, statewide, microcracking could potentially save TxDOT (10,102 × $589) $5.95 million annually in NPV costs. For an anticipated effectiveness of microcracking ranging from 30 to 70 percent, Figure 4.4 shows the range of estimated potential yearly NPV savings to TxDOT with varying levels of implementation. TxDOT should consider more widespread use of microcracking; the future economic benefits by reduced quantities of crack sealing could provide substantial cost savings to the department. Even a 25 percent implementation could save between $1 and $2 million in yearly NPV costs.

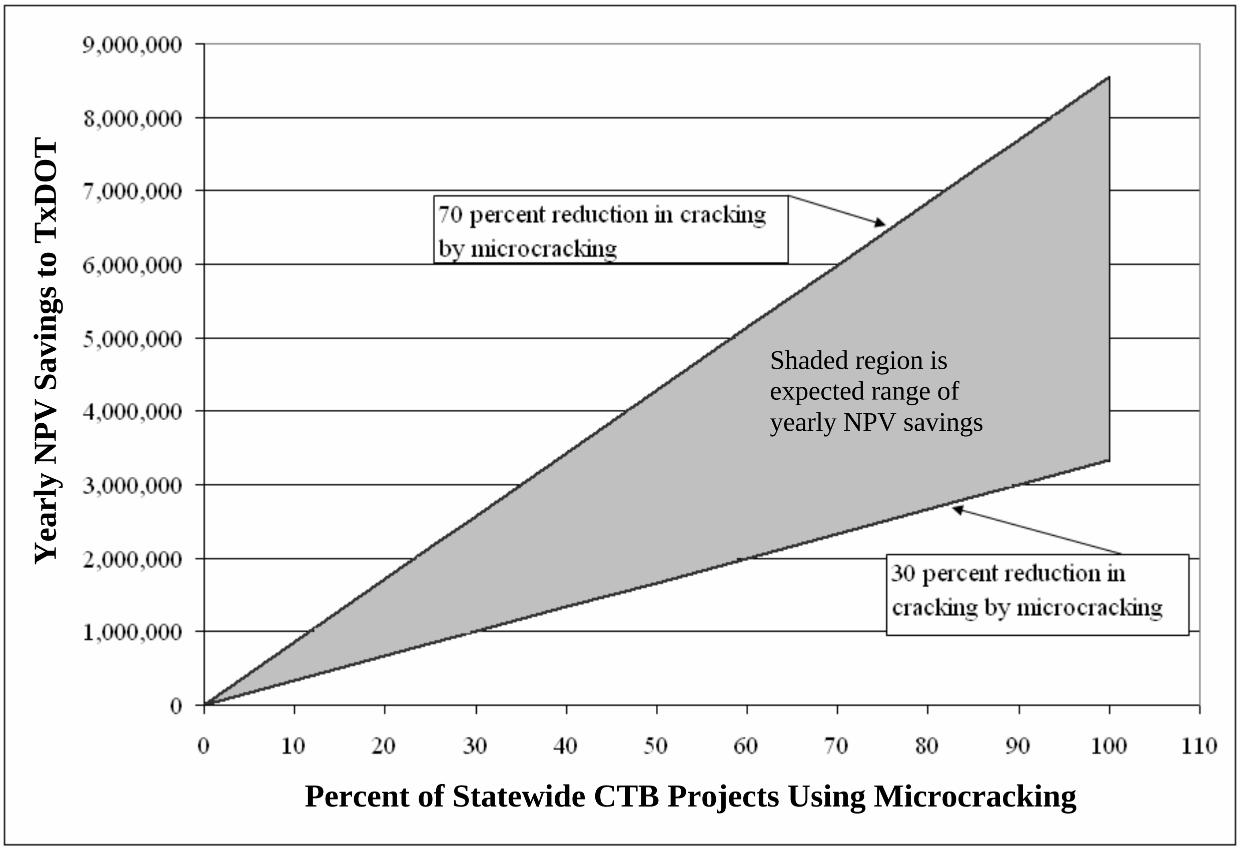


Figure 4.4. Estimated Yearly NPV Savings by Microcracking.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Based upon the results obtained during this research project, microcracking can be considered a valid method for improving the cracking performance of cement-treated bases. Microcracking, applied by a vibratory steel wheel roller to the CTB at a short curing age, typically after one to three days, improves the cracking performance by reducing crack width and severity. The best performance at controlled test sites has been observed at the site microcracked after two days curing.

Microcracking alone is not sufficient to drastically improve crack performance. Combining microcracking with new mixture design approaches provides the best opportunity to realize significantly improved crack performance. Currently, a mixture design approach using a target 7-day unconfined compressive strength of 300 psi, concurrent with passing criteria for adequate resistance to moisture, is recommended. A variant of the Tube Suction Test is one such moisture susceptibility test *(4)*.

Observations noted during this project indicated that in cooler construction conditions, two days curing was not deemed long enough before initiating microcracking. On one construction project when average daily temperatures were below 60 °F, the base was cured for four days prior to microcracking. Based upon these experiences, guidelines for microcracking were revised and resubmitted to TxDOT. The Appendix of this report presents these guidelines.

Microcracking can produce significant monetary savings to TxDOT by reducing the quantity of future crack-sealing operations. An average reduction in cracking of 50 percent was estimated from this project; even implementing microcracking on 25 percent of TxDOT CTB projects could save the department approximately $1.5 million in yearly net present value costs.

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2. Brandl, H. Mixed in Place Stabilisation of Pavement Structures with Cement and Additives, *Proceedings*, XIIth European Conference on Soil Mechanics and Geotechnical Engineering, Rotterdam, Netherlands, 1999.
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4. Scullion, T., S. Sebesta, P.P. Harris, and I. Syed. A Balanced Approach to Selecting the Optimal Cement Content for Soil-Cement Bases, Report 404611-1, Texas Transportation Institute, College Station, TX, 2000.

APPENDIX

UPDATED GUIDELINES FOR MICROCRACKING

How and When Should Microcracking be Performed?

After placement and satisfactory compaction of the CTB according to the applicable bid item, the base should be moist cured by sprinkling for 48 to 72 hours before microcracking. If performing microcracking during winter months when average daily temperatures are 60 °F or below, moist cure the base for at least 96 hours before microcracking. Microcracking should be performed with the same (or equivalent tonnage) steel wheel vibratory roller used for compaction. A minimum 12-ton roller should be used. Typically three full passes (one pass is down and back) with the roller operating at maximum amplitude and traveling approximately 2 to 3 mph will satisfactorily microcrack the section. After satisfactory completion of microcracking, the base should be moist cured by sprinkling to a total cure time of at least 72 hours from the day of placement

What to Look for during the Microcracking Process

Inspect the microcracking operation and look for:

- Satisfactory completion of three full passes that achieve 100 percent coverage.
- Signs of cracking in the CTB. Although new cracks are rarely observed (oftentimes some transverse cracking will have already taken place during the moist-curing stage), hairline cracks imparted by the roller occasionally may be visible. If available, the FWD can be used to ensure adequate completion of microcracking by testing every station immediately before microcracking, then retesting at each station immediately after completion of the three microcracking passes. The average base modulus should be reduced at least 50 percent by microcracking with three passes of the roller.
- Signs of detrimental damage to the CTB. If properly designed and cured, microcracking should not damage the CTB. However, if the base appears to start to break up excessively at the surface, stop microcracking and use a static roller until a satisfactory surface finish is obtained.
- Satisfactory completion of continued moist curing to an age of at least 72 hours from the day of placement.