In-Place Cement Stabilized Base Reconstruction Techniques
Interim Report: “Construction and Two Year Evaluation”

by

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ABSTRACT

The purpose of this research was to evaluate the effectiveness of soil cement shrinkage crack mitigation techniques. The contents of this report reflect an evaluation of the construction of the test sections and a two-year evaluation of the test sections. This was accomplished through a four-part program that consisted of constructing test sections, laboratory evaluation of materials, structural evaluation of test sections, and crack mapping the soil cement base course and asphaltic concrete pavement.

Ten test sections were constructed on LA 89, State Project number 397-04-0004. Each test section was 1,000 feet long. The shrinkage crack mitigation methods that were addressed included cement content, base thicknesses, fibers, interlayer, curing membrane, and curing periods.

Since reflective cracks were not observed during the 1.8 year monitoring period, no conclusions can be drawn as to the effectiveness of the different shrinkage crack mitigation methods used. However, based on the cost of construction, the sections may be ranked: 1) cement stabilized and treated base course, 2) cement stabilized base course with crack relief layer or E.A. curing membrane with sand, 3) cement stabilized base course with 0.05 percent fibers, 4) cement treated base course with 0.05 percent fibers, 5) cement stabilized base course with 0.1 percent fibers, and 6) cement treated base course with 0.1 percent fibers.

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IMPLEMENTATION STATEMENT

The results of this study indicated that cement treated base course is an economically feasible method of mitigating shrinkage cracks. This research can be used to encourage the use of cement treated base courses in lieu of cement stabilized base courses unless conditions warrant otherwise.

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INTRODUCTION

The Louisiana Department of Transportation and Development (DOTD) is undergoing a major budget shift from construction on new alignments to maintaining existing infrastructures. A large percentage of DOTD's current construction budget is targeted for rehabilitation of existing asphalt surfaced roadways built on soil cement bases. In fiscal year 1999 – 2000, DOTD spent $160 million on its rural overlay program. Reconditioning the existing soil cement base courses with additional cement is used extensively because of its cost effectiveness ($4 to $5 per square yard). However, there are problems associated with stabilizing or restabilizing soil cement bases. These include, but are not limited to, excessive shrinkage cracks (transverse and longitudinal) and premature base failures.

Soil cement is a composite material of pulverized soil, Portland cement, water, and possibly admixtures compacted to a high density to form a hardened structural material with specific engineering properties *[1].* It has been used throughout the world to enhance the strength characteristics of bases for roadways, parking lots, and buildings. When Portland cement is blended with water and soil and compacted, a hydration process and chemical alteration of the soil begins. The hydration process forms a paste which acts like a glue to hold the soil particles together. This mixture hardens to form a rigid material that is durable and resistant to rutting. Unfortunately, the hardening process also causes the material to contract, which produces shrinkage cracks *[2], [3]*.

Factors that can influence shrinkage cracking in soil cement bases are cement content, moisture content, density, compaction, curing, and fine grain soils *[1], [2].* In concrete pavement, the shrinkage due to hydration and thermal expansion/contraction is typically mitigated with joints and reinforcement. Soil cement is basically a low grade concrete slab. It has no reinforcement or joints to counteract stresses and therefore must rely on the tensile strength of the material and friction with the underlying soil to resist shrinkage *[2], [4].*

The purpose of this study is to determine the effectiveness of the following reflective crack mitigation techniques: 1) cement content, 2) base course thicknesses, 3) fibers, 4) interlayers, 5) curing membranes, 6) curing periods. This was accomplished by conducting a comprehensive laboratory evaluation study, a technical assistance study, and constructing test sections on LA 89 in Vermilion Parish *[5], [6].* This interim report presents the evaluation of the construction and two-year evaluation of LA 89 field test sections. The sections will continue to be monitored and a final report will be issued at the project's conclusion.

OBJECTIVE

The purpose of this research was to evaluate the effectiveness of soil cement shrinkage crack mitigation techniques. This was accomplished through a four-part program that consisted of constructing test sections, laboratory evaluation of materials, structural evaluation of test sections, and crack mapping the soil cement base course and asphaltic concrete pavement.

SCOPE

Ten test sections were constructed on LA 89, State Project number 397-04-0004. Each test section was 1,000 feet long. The shrinkage crack mitigation methods that were addressed included cement content, base thicknesses, fibers, interlayer, curing membrane, and curing periods.

Soil samples were taken from each test section after pulverization and prior to the addition of cement. These samples were used to conduct experiments in the laboratory. The samples were subjected to unconfined compression tests, durability tests, indirect tensile and strain, and indirect tensile resilient modulus tests.

During construction of the test sections, samples were acquired. Specimens were molded in the field and transported to the Louisiana Transportation Research Center (LTRC). The specimens were subjected to unconfined compression and durability testing.

After the test sections were constructed, their structural properties were assessed with the Dynaflect and FWD. Crack mapping was conducted by field technicians and the pavement management section with ARAN.

METHODOLOGY

Test Sections Design

The purpose of this study is to compare the effectiveness of different reflective crack mitigation techniques. The variables that were addressed included cement content, base thickness, fibers, interlayer, curing membranes, and curing periods. Table 1 illustrates the locations of the test sections and Appendix 1 contains the special provisions used for the construction of them. Soil cement stabilization was conducted in accordance with Section 303 of the 1992 edition of the Louisiana Standard Specifications for Roads and Bridges.

Table 1
Test sections

Test Section	Thickness Inches	Cement Content	Fiber Content	Overlay Period	Description / Station location
1	8.5	9%	N/A	< 7 days	**Control Section – CSD** Sta. (5+00 to 15+00)
2	8.5	9%	0.1%	< 7 days	**CSD with fibers** Sta. (15+00 to 25+00)
3	8.5	9%	0.05%	< 7 days	**CSD with fibers** Sta. (25+00 to 35+00)
4	12	5%	N/A	< 7 days	**CTD** Sta. (35+00 to 45+00)
5	12	5%	0.1%	< 7 days	**CTD with fibers** Sta. (45+00 to 55+00)
6	12	5%	0.05%	< 7 days	**CTD with fibers** Sta. (55+00 to 65+00)
7	8.5	9%	N/A	< 7 days	**Crack Relief Layer – CSD** Sta. (65+00 to 75+00)
8	8.5	9%	N/A	< 7 days	**E.A. Curing Layer w/sand CSD** Sta. (75+00 to 85+00)
9	8.5	9%	N/A	14 to 30 days	**Extended Cure Period – CSD** Sta. (85+00 to 95+00)
CSD - Cement stabilized design * CTD - Cement treated design *					

E.A. - Emulsified asphalt * defined in (Cement content and base thickness)

Cement Content and Base Thickness. There are two types of soil cement designs used by DOTD: stabilized cement design and cement treated design. Cement stabilized design (CSD) is governed by DOTD TR 432M/432-99. The current practice is to determine the percentage of cement that produces a compressive strength of 300 psi at seven days for soil aggregate or recycled bases. It is generally used with 8.5 inch thick base courses. Cement treated design (CTD) refers to materials blended with low cement contents (four to six percent) and a minimum seven day compression strength of 150 psi. It is generally used with base courses that are 12 inches thick. Test sections were built using both design methods. These sections also doubled as control sections to gauge the performance of the other sections.

Fibers. When properly mixed with soil cement, polypropylene fibers should open up or filamentize to form a net reinforcing configuration that interlocks with the soil cement mixture. Its appearance resembles a high density synthetic root system that penetrates into the soil mass. Properly mixed fibers should improve both the shear and tensile strength of the soil cement. This could enhance the long term performance of the base course and reduce shrinkage cracks. Gaspard et.al., Mohammad et.al., Sobhan et.al., and Maher et.al. found that fibers do not increase the peak unconfined compressive strength but do increase the tensile strength-strain, resilient modulus, and toughness index of the soil-cement-fiber mixture *[5], [7], [8], [9].*

Fibers were used at concentrations of 0.1 and 0.05 percent in both CSD and CTD sections. The material properties of the fibers used in this study are illustrated in table 2.

Interlayers. Test section 7, crack relief layer, was designed and constructed in accordance with Section 507 of the Louisiana Standard Specifications for Roads and Bridges, 1992 edition (LASPEC). It was a 0.5 inch-thick asphalt surface treatment layer (ASTL). The ASTL acts as an interlayer that forms a barrier between the soil cement base course and asphalt pavement. Its purpose is to prevent shrinkage cracks from propagating into the asphalt pavement. The effectiveness of interlayers has been described by Kuhlman and Morris et.al. *[2], [10].*

Curing Membrane. Test section 8 was constructed to determine the impact of applying a thicker emulsified asphalt curing membrane on shrinkage cracks. Excessive moisture loss during the initial hydration process has been shown to weaken the soil cement and cause excessive shrinkage cracks *[1], [2], [11].* Section 506, Asphalt Curing membrane, of the LASPEC was modified to increase the dosage rate of emulsified asphalt from 0.1 gallons per square yard to 0.2 gallons per square yard. Additionally, a 0.25 inch-thick layer of sand was added to the curing membrane to prevent the emulsified asphalt from flowing off of the pavement. Kuhlman reported that adding sand to the emulsion could help keep the curing membrane functional especially if the soil cement was subject to traffic loading prior to the asphaltic concrete overlay *[2].*

Curing Period. Test section 9 was constructed to monitor the effect of an extended cure period on shrinkage crack propagation. Kuhlman reported that soil cement base courses should be allowed to cure for at least seven days prior to being overlaid with asphaltic concrete *[2].* It is believed that as much as 80 percent of shrinkage cracks from cement hydration occur within the first two weeks of curing. Therefore, if the pavement is placed after most of the shrinkage cracks have occurred, then fewer shrinkage cracks should propagate into the asphalt pavement. To accurately monitor this, test sections 1-8 were overlaid with asphalt within seven days after being stabilized and test section 9 was specified to be overlaid between fourteen and thirty days.

Table 2

Fiber properties

Properties	Test Method	Requirements
Polypropylene	ASTM D4101 Group 1/Class 1/Grade 2	99.4%
Specific Gravity	ASTM D792	0.91
Tensile Strength	ASTM D2256	45 ksi
Ultraviolet Resistance	-	Nil
Moisture Absorption	-	0.6%
Elongation (%)	ASTM D2256	15.5
Modulus of Elasticity	ASTMD2101	700 ksi
Denier	-	360

Materials and In-place Base Course Assessment

LTRC Laboratory prepared specimens. Soil samples were acquired after the existing base course was pulverized. Cement and fiber samples were taken from the project site and used to create soil cement and soil-cement-fiber specimens in the laboratory. The field moisture density curves were obtained from the project engineer. The laboratory-prepared specimens were prepared at the moisture content of the field test sections even if it was different from the optimum moisture content for that section.

This allowed the material to be evaluated as it was constructed. These specimens were subjected to unconfined compression, durability, indirect-tensile-resilient-modulus, and indirect-tensile-strain tests. Table 3 illustrates the testing factorial for laboratory-prepared specimens.

Field Laboratory-Prepared Specimens. Soil samples were acquired from the soil-cement and soil-cement-fiber stabilized test sections during their construction. The field laboratory was used to prepare specimens in accordance with ASTM D1633 and DOTD TR 432M/432-99. Specimens were prepared in 4- and 6-inch proctor molds. This variation allowed a comparison of the compressive strengths obtained from different mold sizes. The specimens were transported to the LTRC laboratory for curing and testing. The testing factorial is identical to the LTRC laboratory-prepared specimens and is also listed in table 3.

Field vs. Laboratory. The test results from the laboratory- and field- prepared specimens were compared to determine if there were any differences. Melancon and Shah found that soil cement base courses achieved only 75 percent of the laboratory designed strength *[12].* Additionally, the effects on the strength characteristics of mixing fibers in the laboratory versus field mixing with a stabilizer were assessed.

Crack Mapping. Crack mapping surveys were conducted before and after the soil cement base course was overlaid with asphaltic concrete. The shrinkage cracks in the base course of each test section were mapped by Dr. K. P. George of Ole Miss University, a well-published expert in the field of soil cement shrinkage *[11,] [13], [14]*. From this data, shrinkage crack formation could be determined for each section built. Additionally, this information could be used to determine the effectiveness of shrinkage crack proprogation through the asphaltic concrete pavement. After the base course was overlaid, crack mapping was conducted annually by either LTRC technicians or the ARAN system.

Table 3

Testing factorial for laboratory- and field- prepared specimens

and in-place base course

Tests	Test Sections								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Layer Coefficient (Dynaflect)	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**
Resilient Modulus (FWD)	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**
UC (1)	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**
Indirect tensile (2)	X	**T**	**T**	X	**T**	**T**	X	X	X
Durability (2)	**T**	X	X	**T**	X	X	**T**	**T**	**T**

(1) 3 specimens were molded in both 4- and 6-inch proctor molds
(2) 6 specimens were molded in 4-inch proctor molds

In-place Base Course Assessment

Dynaflect and Structural Number

The Dynamic Deflection Determination system (DYNAFLECT) is a trailer mounted device which induces a dynamic load on the pavement and measures the resulting slab deflections by use of geophones spaced under the trailer at approximately one- foot intervals from the application of the load. The pavement is subjected to a 1,000 pound dynamic load at a frequency of eight cycles per second, which is produced by a counter rotation of two unbalanced flywheels. The generated cyclic force is transmitted vertically through two steel wheels spaced 20 inches apart, center to center. The dynamic force during each rotation of the flywheels at the proper speed varies from 1,100 to 2,100 pounds. The deflection measurements induced by the system are expressed in terms of milli-inches of deflection. Through a series of equations and graphs, the structural number (SN) is determined. The layer coefficient, which is the structural number divided by the thickness of base layer, used for soil cement base courses in flexible pavement design by DOTD is 0.14 SN/in. The structural number represents the ability of a flexible pavement to withstand the projected axle loading. The formula for the structural number is the sum of the structural numbers for each layer in the pavement section and is listed below *[15]:*

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

a_1, a_2, a_3 = layer coefficients (SN/in.) representative of surface, base, and subbase courses, respectively.

D_1, D_2, D_3 = actual thicknesses (in) of surface, base, and subbase, respectively.

m_2, m_3 = drainage coefficients for base and subbase layers, respectively.

Test zones for each test section were 1000 feet long. Segments measuring 100 feet were established in each test zone for Dynaflect readings. Ten readings were taken in each segment. The Dynaflect provides the structural number of the layers below it. It does not distinguish between layers such as subbase and base. In order to acquire the structural number of the base course (SN_2), two readings were taken. One reading was taken on the subbase (SN_3) and the other was taken on the stabilized soil cement base course (SN_{3+2}). The structural number for the soil cement base course was determined by subtracting (SN_3) from (SN_{3+2}). The layer coefficient (a_2) for the soil cement base course was determined by dividing (SN_2) by the thickness (d_2) of the base course.

$$\mathbf{SN_2 = SN_{3+2} - SN_3}$$

$$\mathbf{a_2 = SN_2 / d_2}$$

FWD and Resilient Modulus

The Falling Weight Deflectometer (FWD) is a device that closely approximates the effect of a moving wheel load, both in magnitude and duration. The 9,000 pound load is applied through a circular plate which causes the pavement to deflect. Once the load is applied, it is measured by a precision heavy duty load cell which is above the loading plate. By means of a high speed transducer, the deflection data is acquired by a computer. Through a back calculation process, the resilient modulus (elastic modulus) is determined for each layer. The resilient modulus (Mr) is a measure of a material's stiffness and can provide an indication of the condition and uniformity of a material. This number was compared to typical values found in stabilized soil cement (200 k.s.i.) and cement treated soil (100 k.s.i.) *[16].*

In flexible pavement design, resilient modulus is one of five variables used to determine the design structural number (SN) *[15].*

Ten FWD readings were taken on each test section and then averaged to provide a representative resilient modulus for that test section. The raw data from the FWD was processed by Dynatest's ELMOD 4 software to obtain the resilient modulus.

DISCUSSION OF RESULTS

Field Construction Analysis

Moisture-Density Curves from Field Laboratory

During the process of construction, DOTD field technicians collected soil samples and performed testing to determine the optimum moisture content and maximum dry density of the soil cement base courses. After the sections were completed, the in-place moisture content and density were determined with a nuclear gauge. These values were used for quality control purposes in accordance with Section 303 of the 1992 edition of the Louisiana Standard Specifications for Roads and Bridges. Each test section met the requirements of Section 303 and the results are presented in table 4.

Table 4

Moisture-density curve results from field laboratory

Test Section	Cement content (%)	Field curve Field point MC (%) (1)	Field curve Dry Density lbs./ft^3 (1)	Field curve Optimum MC (%)	Field curve Maximum Dry Density lbs./ft^3
1	9	21.6	100.2	21.8	100.2
2	9	23.6	97.9	24.2	98.9
3	9	24.3	96.4	23.2	97.3
4	5	22.9	99.0	20.0	97.0
5	5	20.6	100.2	21.0	101.0
6	5	22.7	96.7	23.5	97.3
7	9	20.4	99.8	21.3	100.4
8	9	21.8	100.8	21.5	100.8
9	9	22.5	96.6	23.3	98.0
10	9	22.6	97.2	22.6	97.6

(1) These are the moisture contents and dry densities of the test sections

Base Course Stabilization

The contractor began cement stabilization on April 21, 1999. The Caterpillar 250 stabilizer was not functioning properly. Some spots in the soil cement were wet and some were dry. Visible streaking across the stabilizer pass was obvious. The contractor was unsuccessful at adjusting this machine. Stations 5+00 to 19+00 had varying amounts of water added to it. It was decided that a new control section would be established because test section 1 had such variable moisture contents. Table 5 illustrates the test sections that were constructed.

Table 5

Test section descriptions

Test Section	Thickness Inches	Cement Content	Fiber Content	Overlay Period	Description / Station location
1	8.5	9%	N/A	< 7 days	**Control Section – CSD** Sta. (5+00 to 15+00)
2	8.5	9%	0.1%	< 7 days	**CSD with fibers** Sta. (15+00 to 25+00)
3	8.5	9%	0.05%	< 7 days	**CSD with fibers** Sta. (25+00 to 35+00)
4	12	5%	N/A	< 7 days	**CTD** Sta. (35+00 to 45+00)
5	12	5%	0.1%	< 7 days	**CTD with fibers** Sta. (45+00 to 55+00)
6	12	5%	0.05%	< 7 days	**CTD with fibers** Sta. (55+00 to 65+00)
7	8.5	9%	N/A	< 7 days	**Crack Relief Layer – CSD** Sta. (65+00 to 75+00)
8	8.5	9%	N/A	< 7 days	**E.A. Curing Layer w/sand CSD** Sta. (75+00 to 85+00)
9	8.5	9%	N/A	< 7 days	**Control Section CSD** Sta. (85+00 to 95+00)
10	8.5	9%	N/A	14 to 30 days	**Extended Cure period – CSD** Sta. (95+00 to 105+00)

From Stations 19+00 to 25+00, a different stabilizer, Caterpillar 650, was used for the initial blending pass. It was followed by two Caterpillar 250 stabilizers. There were still some visible wet and dry streaks in the soil cement base course. Moisture content tests were taken at various locations to catalog the variations. The results are listed in Appendix 2. The soil was very moisture sensitive. It would liquefy quickly once the optimum moisture content was exceeded. These problems were corrected and the stabilizers performed satisfactorily on the remaining test sections.

Fiber Installation

The procedures outlined in the special provisions (Appendix 1) for fiber installation were modified. In order to conduct a continuous cement stabilization operation, the contractor elected to blend the fibers into the base course on test sections 2, 3, 5, 6 and then begin cement stabilization at test section 1. In order to accommodate traffic during construction and prevent motorists from driving on the fibers, one lane was constructed at a time. The contractor computed the dosage rates for each test section. The bags were transported to the roadway area by forklift. It took two construction workers for this operation. The bags of fibers were then placed on the road at calculated distances to obtain the specified dosage rates. The bags were opened and spread with garden rakes by seven construction workers.

The stabilizer was constantly waiting on the fiber-spreading construction workers. It took approximately 6 hours to progress 3,000 feet on one lane. For the operation to be feasible on a larger project, a better method for fiber placement needs to be developed. Fiber mixing with the stabilizer went smoothly with no clustering of fibers on the stabilizer's mixing apparatus.

Crack Relief Layer

The asphalt surface treatment layer was placed over the soil cement base course three days after it was completed. The chip seal spreader was not functioning properly. The aggregate spreader was not covering some areas so the asphalt emulsion was balling up on the tires. Some areas had to be covered by hand shoveling aggregate over sparsely covered areas. The chip seal appeared to be adequate for the purpose of a crack relief layer.

E.A. Curing Membrane with Sand

The specifications required the contractor to place this membrane within one day of the base course construction. However, the sand curing membrane was placed six days after the construction of the soil cement base course section due to equipment breakdowns. The normal curing membrane was applied each day until the sand layer was placed. Once construction began, the chip seal spreader still would not function properly; so the sand was placed manually. The sand membrane looked adequate and appeared to form a thicker layer than the regular curing membrane used on the project.

Construction Cost Analysis

Table 6 presents the construction costs for the soil cement base course and interlayers. In terms of cost, the sections may be ranked as follows:

1. Cement stabilized and cement treated design sections
2. Cement stabilized design with crack relief layer or E.A. curing membrane with sand
3. Cement stabilized design with 0.05 percent fibers
4. Cement treated design with 0.05 percent fibers
5. Cement stabilized design with 0.1 percent fibers
6. Cement treated design with 0.1 percent fibers

The crack relief layer or E.A. membrane with sand adds about $3.00 per square yard to the cost of base course construction. The cost increase due to the inclusion of fibers ranged from $6.90 to $16.29 per square yard.

Table 6

Construction costs

Test sections - Description	Cost($) per square yard				
	Cement stabilizing (1)	Fibers (2)	Crack relief layer	Curing mem. w/sand	Total
1. CSD	4.05	---	---	---	4.05
2. CSD with 0.1% fibers	5.85	10.19	---	---	16.04
3. CSD with 0.05% fibers	5.85	5.10	---	---	10.95
4. CTD	4.35	---	---	---	4.35
5. CTD with 0.1% fibers	6.24	14.40	---	---	20.64
6. CTD with 0.05% fibers	6.24	7.20	---	---	13.44
7. CSD with crack relief layer	4.05	---	3.00	---	7.05
8. CSD with E.A. curing layer with sand	4.05	---	---	3.05	7.10
9. Control section (CSD)	4.05	---	---	---	4.05
10. CSD with extended cure period	4.05	---	---	---	4.05
CSD - 9% cement content and 8.5 inches thick CTD - 5% cement content and 12 inches thick					

(1) includes cost of cement
(2) actual cost of fibers exclusive of mixing with soil cement base course

Crack mapping base course and asphalt pavement

Crack Mapping Base Course

Dr. K.P. George conducted a crack mapping survey of the base course and the results are listed in table 7 and graphically presented in figure 2. The most substantial amount of shrinkage cracking occurred in test sections 2, 3, and 6, all of which contained fibers.

However, test section 5 also contained fibers and exhibited minimal shrinkage cracks.

Test section 9, the control section, exhibited only 6-feet of shrinkage cracks.

Table 7

Base course shrinkage crack survey

Test Section	Description	Date Constructed	Date Surveyed	Shrinkage Cracks, ft.		
				L*	M*	H*
1	CSD	4-21-99	4-30-99	135	86	13
2	CSD with fibers	4-21-99	5-1-99	544	79	32
3	CSD with fibers	4-22-99	5-1-99	742	117	---
4	CTD	4-22-99	5-1-99	268	75	---
5	CTD with fibers	4-22-99	5-1-99	30	3	---
6	CTD with fibers	4-26-99	5-1-99	434	41	---
7	Crack Relief Layer CSD	4-26-99	5-1-99	***	***	***
8	E.A. Curing Layer w/sand - CSD	4-26-99	5-1-99	44	8	---
9	Control Section CSD	4-28-99	5-1-99	6	---	---
10	Extended Cure Period - CSD	4-28-99	5-1-99	22	---	---

* L = (width < 1.5 mm); M= (1.5< width (mm)<3); H= (width> 3mm)

*** not surveyed since it was covered with a crack relief layer

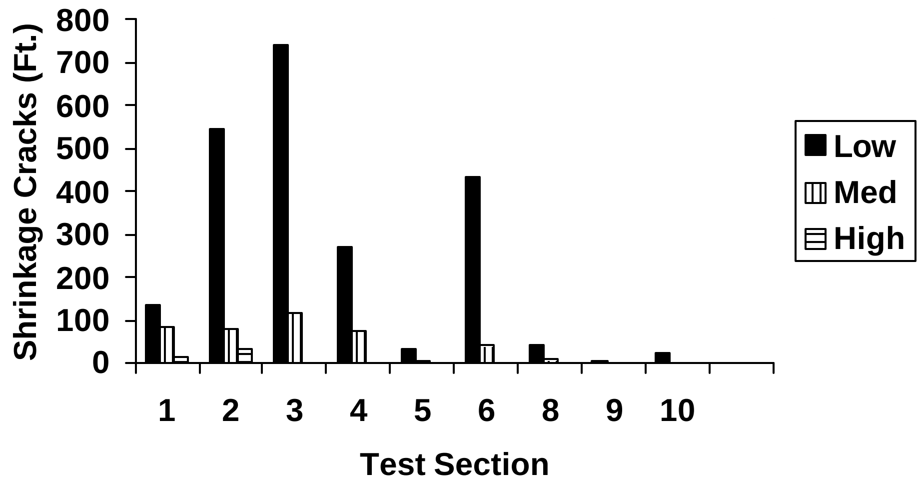

Figure 1

Base course crack mapping

Crack Mapping Asphaltic Concrete

The test sections were overlaid in May 1999. LTRC technicians conducted crack mapping surveys on October 19, 1999, and December 11, 2000. The Pavement Management group provided crack mapping data from the ARAN system which was conducted on March 13, 2001. During the three surveys, shrinkage cracks were not observed.

Discussion. Even though shrinkage cracks were observed on the base course, proprogation of cracks through the asphaltic concrete pavement were not observed through a 1.8 year period. Therefore, to date, no conclusions can be drawn as to the effectiveness of shrinkage crack mitigation methods used in this study. Monitoring will continue for a period of five years.

In-Place Base Course Assessment

Layer Coefficient and Resilient Modulus

Table 8 illustrates the results of the Dynaflect and FWD tests on the soil cement base course.

Table 8

Layer coefficient and resilient modulus results

Test section	Description	LC 4-28-99	LC 5-3-99	Mr 10-1-99	Mr 7-16-02
1	SCD	0.24	0.22	250	315
2	SCD with 0.1% fibers	0.25	0.19	222	362
3	SCD with 0.05% fibers	0.27	0.22	182	217
4	CTD	0.18	0.12	265	410
5	CTD with 0.1% fibers	0.09	0.09	230	200
6	CTD with 0.05% fibers	0.18	0.16	270	255
7	Crack Relief Layer	0.22	0.21	241	318
8	E.A. Curing Layer w/sand	0.20	0.22	276	328
9	Control Section	0.21	0.28	257	308
10	Extended Cure Period	---	0.21	236	431
LC = Layer coefficient (SN/in.) from Dynaflect Mr = Resilient Modulus from FWD					

Layer Coefficient

The base course was measured twice with the Dynaflect. On April 28, 1999, nine out of the ten test sections exceeded the 0.14 SN/in. design value. Test section 5 had a layer coefficient of 0.09. It is believed that this value was lower than the others because the subgrade measurement was much stronger under this test section than the others. Since the Dynaflect uses a cyclic load of only 1,000 pounds, a strong subgrade layer can mask the stiffness of the base course layer. On May 3, 1999, eight out of the ten test sections exceeded the 0.14 SN/in. design value. It should be noted that there was a trend toward a lower layer coefficient for most test sections. This could be due to the fact that traffic is allowed on the base course prior to being overlaid with asphaltic concrete.

Resilient Modulus

The resilient modulus of the base course was measured on two separate occasions with the FWD. On both occasions, each test section met or exceeded the 100 to 200 ksi design values *[16]*. It is interesting to note that fibers were shown to increase the resilient modulus from laboratory tests *[5]*. However, the in-place resilient modulus testing with the FWD did not show that fibers increased the resilient modulus on the test sections.

Laboratory assessment of materials

While testing both field- and laboratory-prepared specimens, an unexpected variance in unconfined compressive strengths and durability tests was encountered. Table 9 illustrates the results of field laboratory-prepared specimens and multiple series of laboratory-prepared specimens. Appendix 3 and table 10 illustrate the soil classifications and the results of specimens prepared in the field laboratory for durability testing, respectively.

Table 9
Summary of unconfined compression tests

Test section	Cement content percent	Fiber content percent	UC (psi) Field prepared May 99 6” mold	UC (psi) Field prepared May 99 4” mold	UC (psi) Lab prepared June 99 4” mold	UC (psi) Lab prepared Jul 99 4”mold
1	9	0	No data	279.8		
2	9	0.10	194.3	228.4	112.1	165.8
3	9	0.05	147.3	159.2	149.9	175.8
4	5	0	120.2	96.3	42.5	249.4
5	5	0.10	241.7	185.4	108.0	339.5
6	5	0.05	183.8	169.9	81.7	232.3
7	9	0	133.4	214.2	214.3	200.5
8	9	0	226.1	294.9		216.2
9	9	0	373.8	410.5		249.9
10	9	0	252.7	308.1		

Table 10
Summary of durability tests

Test section 4	
A1 – broke after the 1st cycle	B1 – used for diameter measurements
A2 – broke after the 5th cycle	B2
A3 – broke after the 1st cycle	B3
Test section 7	
A1 – broke after 4th cycle	B1– used for diameter measurements
A2 – broke after 1st cycle	B2
A3 – broke after 4th cycle	B3
Test section 8	
A1 – weight gain of 3.13%	B1 – weight gain of 1.32%
A2 – weight gain of 3.45%	B2 – weight gain of 1.97%
A3 – weight gain of 3.23%	B3 – weight gain of 1.44%
Test section 9	
A1 – weight gain of 3.62%	B1 – weight gain of 2.22%
A2 – weight gain of 3.90%	B2 – weight gain of 2.43%
A3 – weight gain of 3.43%	B3 – weight gain of 2.79%
Test section 1	
A1 – broke after 5th cycle	B1– used for diameter measurements
A2 – broke after 2nd cycle	B2
A3 – weight gain of 2.56%	B3 – weight loss of 0.87%

Discussion. Test sections 2 – 7 showed a lower than expected unconfined compressive strength in both the four- and six-inch diameter specimens. The nine and five percent cement content specimens should have yielded strengths in the 300 and 150 psi range, respectively. Two series of additional unconfined compressive strength testing were conducted in June and July of 1999 as illustrated in table 9. Both showed large variations between tests as well as low unconfined compressive strengths.

Additionally, as shown in table 10, approximately half of the durability samples broke during the testing process while the remainder of the samples gained weight. The purpose of the durability test is to monitor the weight loss and diameter change of specimens during the 12 cycles of wetting, drying, and brushing. Weight gains during the process had never been encountered before by LTRC. PH and sugar tests were conducted on the soils. The soils tested negative for sugar and the PH levels were in acceptable ranges.

Due to the problems encountered, it was decided to have a comprehensive mineralogical study conducted on the soil and cement that was used to manufacture the specimens.

Mineralogical Study

Dr. Amitava Roy, an expert in cement and mineralogy at Louisiana State University, was contracted through the Engineering Materials Characterization Research Facility at LTRC to perform this work *[17].*

The results of Dr. Roy's testing did not provide any mineralogical explanation for the large variation in unconfined compressive strengths and failures in durability specimens. It did, however, offer an explanation for the weight gains in the durability specimens. The formation of calcium carbonate during the wetting and drying process caused a weight gain in the durability specimens.

Discussion. In addition to the previously mentioned specimen testing variations, the indirect tensile-strain and resilient modulus testing also indicated unusual variances in the results. Therefore, due to the variability in tests results encountered, all materials testing in the laboratory is considered invalid and no conclusions will be offered.

CONCLUSIONS

To date, reflective cracks through the asphaltic concrete pavement have not been observed. Therefore, an analysis of the effectiveness of different shrinkage crack mitigation techniques is impossible at this time. LTRC will continue to monitor the test sections for a period of five years. At that time, a final report will be issued.

The in-place base course assessment with the Dynaflect and FWD indicated that the test sections produced layer coefficients and resilient moduli that met or exceeded design standards and were consistent with other projects in Louisiana *[4].*

The cement stabilized and treated sections, and the crack relief layer (asphalt surface treatment) were constructed with normal DOTD procedures. The E.A. curing membrane with sand was difficult to construct with the methods used. In order for it to be feasible, a better method for placing a thin layer (0.25 inches thick) of sand over the E. A. curing membrane needs to be developed. Fibers can be mixed into the soil easily with the stabilizer. However, the placement of fibers prior to mixing with the soil is tedious and labor intensive. A better method for distributing fibers needs to be developed. Even though moisture content control problems were encountered during construction in test sections 1 and 2, adverse effects on the performance of the pavement structure were not observed.

The addition of a crack relief layer (asphalt surface treatment) or curing membrane with sand adds about \$3.00 per square yard to the base course. The cost increase due to the inclusion of fibers ranged from \$6.90 to \$16.29 per square yard. Due to this higher cost, fibers are economically unfeasible to use in soil cement base courses.

RECOMMENDATIONS

Cement-treated base courses have been evaluated on LA 89 and other routes *[4].* The results of the analysis has shown that cement treated bases perform as well as cement stabilized bases. Of the shrinkage crack mitigation methods used in this study, cement-treated bases are economically the most feasible and should be used unless conditions warrant otherwise. The crack relief layer (asphalt surface treatment) is preferable to the E.A. curing membrane with sand because a device is available to place it appropriately and quickly. Due to the increased cost of constructing a base course with fibers ($6.90 to $16.29), fibers are economically unfeasible to use.

Since reflective cracks were not observed during this monitoring period (May 1999 to March 2001), it is recommended that additional test sections be constructed to the monitor their performance.

ACRONYMS, ABBREVIATIONS, & SYMBOLS

CTD	Cement treated design
CSD	Cement stabilized design
Fibers	Fibrillated polypropylene fibers
LC	Layer coefficient
Mr	Resilient modulus
UC	Unconfined compression

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APPENDIX 1

Special Provisions

Section 507 is amended as follows:

Subsection 507.01, Description: The second paragraph is deleted and the following substituted:

Asphaltic Surface Treatment shall consist of one application of modified asphalt applied at a temperature recommended by the manufacturer. This special provision is intended for use for all type surface treatments and interlayers. The design application rate should be 0.30 gallons/square yard for size 2 aggregate. The application rate may vary depending on the condition of the roadway. The Engineer must approve any change in application rate. All aggregate shall be precoated with a paving grade asphalt cement or CMS-2 or CSS-1h emulsion. The residual asphalt content shall be a minimum of 1.0 percent by weight of the aggregate. The precoat applicator shall submit a certificate certifying the quantities used in the process. The precoat application shall not prevent a free flow of aggregate through the spreader. The gradation requirements apply to the aggregate prior to precoating. The precoat shall serve as a moisture barrier. If an emulsion is used for precoating, the stockpiled precoated aggregate should be cured prior to use. The aggregate application rate shall meet the requirements of Section 507, Table 5.

The finished asphalt shall be smooth and homogeneous and shall comply with the following requirements, either Alternate 1 or Alternate 2: (Specification

Tables Follow).

Subsection 507.06, Application: Before the Asphaltic Surface Treatment operation begins the contractor shall calibrate and set the flow rates of his distributor and spray bar along with the aggregate spreader at a remote location offsite in a manner acceptable to the Engineer.

Hot Applied Modified Asphalt for AST
ALTERNATE 1

		Test Method
Viscosity[2] @ 60EC, 1 sec^{-1}, Poises, Min.	1,000	ASTM D-4957
Viscosity @ 135EC,10 sec^{-1}, Poises, Min.	7	ASTM D-4957
Softening Point, EC	60+	
Flash Point, EC	246+	ASTM D-92
Penetration @ 25EC, 100g, 5 sec, dmm. Min.	55	ASTM D-5
Vis. ATFOT/Vis. BTFOT, ma	2.5	
Solubility %	99.0+	ASTM D-2042

NOTE: The application temperature listed in Table 5 of section 507 is hereby adjusted to 300-360EF for Alternate 1. (Normal application temperature is 330^{o} +/- 10).

[1] Handling of all samples for testing shall be in accordance with ASTM D-4957 Section 7.2, which requires heating the sample in an oven maintained at 383^{o} +/- 4

^{o}F. Stir the sample occasionally until homogenous anpour in suitable container for testing. Pouring temperatures should be 356^{o} $^{+/-}$ 4 ^{o}F (180^{o} +/- 2 ^{o}C)all tests.

[2] Normally run using #200 Modified Koppers Viscometer tube at 300 mm of vacuum.

[3] Normally run using a #50 Modified Koppers Viscometer tube at 100 mm of vacuum.

Storage, Heating, and Application Temperatures in the Alternate 1 is supplemented by the following: Maximum Allowable, For Heating and Storage

<u>Maximum, F</u> = 380^{o}

**   Normal storage temperature is 340^{o} +/- 20^{o} F.

Hot Applied Modified Asphalt for AST
ALTERNATE 2

% Tire Rubber, Min.		5
Viscosity @ 60EC, poises	Min.	1500
Viscosity @ 135EC, cSt	Max.	2000
Penetration @ 25EC	Min. Max.	75 125
Flash Point, EC, COC	Min.	276
Softening Point, EC	Min.	45
Test on RTFO Residue:		
Elastic Recovery @ 4 EC 10cm elongation, % Min.		55
Retained Penetration Ratio (TFOT RESIDUE PEN, 25EC) (Original Pen, 25EC)	Min. Max.	0.60 1.00
Separation Test Settlement/Rubber 325EF, 48 hours softening point max % diff between top and bottom		4.0

NOTE: The application temperature listed in Table 5 of section 507 is hereby adjusted to 300-360EF for Alternate 2

ITEM S-001 THRU S-004 (IN-PLACE CEMENT STABILIZED BASE COURSE WITH FIBER REINFORCEMENT): These items shall be constructed in accordance with Section 303 of the standard specifications except as modified herein.

Materials:

(1) Polypropelene Fiber Reinforcement: Material specifications shall be in accordance with Item S-010, Polypropylene Fiber Reinforcement.

(2) Cement: Shall be in accordance with Section 303 of the Standard Specifications.

Construction Methods:

1. **Fiber Reinforcement Test Areas**: A trial area to determine the construction procedures for each test section shall be made at or near each test section as directed by the project engineer. The trial area shall be approximately 25 square feet. The trial area shall be prepared and mixed in accordance with these specifications and using the same construction equipment and methods as will be used for the actual base course sections. The contractor shall provide a qualified and experienced representative from the fiber manufacturer for a minimum of three days to assist the contractor and DOTD inspectors during construction of the test areas. The representative shall also be available on an as needed basis, as

requested by the project engineer, during the construction of the remaining base course sections.

2. **Fiber dosage rate**: The fiber dosage shall be a rate as specified on the plans. (0.2% fiber dosage rate yields (5.4 lbs fibers/cu.yd. for a dry soil rate of 100 lbs./cu.ft.)) The bags of fiber shall be laid out over the excavated soil in a grid pattern with the amount of fibers calculated based on the volume of soil.

3. **Mixing:** Mixing of the base material shall be accordance with Section 303.05 except as follows. The contractor shall manually open the bags and uniformly spread the fibers over the area to be stabilized. The fibers shall be spread with the use of lawn rakes in order to achieve a uniform spread as directed by the project engineer. The mixing of the fibers and base material shall be achieved by a minimum of three passes with approved equipment as outlined in Section 303. First, after the base material has been prepared and pulverized in accordance with Section 303.04, the fibers shall be spread as indicated above and then mixed with the soil. Second, the cement shall be placed as outlined in Section 303 and mixed with the soil and fiber composite mix. Third, the soil, fiber, and cement mixture shall be mixed again which constitutes three passes. Additional mixing passes may be required to obtain an effective fiber-soil-cement mix as directed by the project engineer. An effect fiber-soil-cement mix shall be attained when the fibers achieve triaxial and three dimensional dispersion without the fibers balling or clumping. Fibrillated fibers should open up or filamentize when properly

mixed to create a filament strand and an net reinforcing configuration that interlocks with the soil cement mix. The appearance of properly opened and filamentized fibers shall resemble a high density synthetic root system that penetrates into the soil mass. The properly mixed fiber reinforced soil should manually demonstrate improved shear strength and cohesion properties as specified by the Materials Laboratory and/or the discretion of the project engineer.

Measurement and Payment:

The items necessary to complete this work shall be measured and paid for as outlined in setion 303 of the standard specifications with the exception that polypropylene fibers shall be measured by the pound and paid for under Item S-010.

Item S-001   In-Place Cement Stabilized Base Course (8.5" Thick) with 0.1% Fiber Reinforcement; per square yard.

Item S-002   In-Place Cement Stabilized Base Course (8.5" Thick) with 0.05% Fiber Reinforcement; per square yard.

Item S-003   In-Place Cement Stabilized Base Course (12" Thick) with 0.1%

Fiber Reinforcement; per square yard.

Item S-004 In-Place Cement Stabilized Base Course (12" Thick) with 0.05% Fiber Reinforcement; per square yard.

Item S-005 Emulsified Asphalt Curing Membrane

Asphalt Curing Membrane:

Section 506 is amended as follows:

The second and third line of Section 506.06 is deleted and the following is substituted: The emulsified asphalt curing membrane shall be uniformly applied at a minimum rate of 0.2 gallons per square yard of undiluted emulsified asphalt and then covered with sand as directed by the project engineer. A minimum of two passes shall be used to achieve this coverage. Emulsified asphalt only shall be used for the curing membrane on this section. On the first pass, emulsified asphalt shall be applied at a minimum rate of 0.1 gallons per square yard and then covered with sand at a minimum rate of 0.0025 cubic yards of sand per square yard of base. The second pass shall repeat the application rates of emulsified asphalt and sand as outlined in the first pass. Before the asphaltic curing membrane operation begins, the contractor shall calibrate and set the flow rates of his distributor and spray bar along with the approved sand spreader on a 25 square yard base location.

Measurement and payment:

The emulsified asphalt shall be measured and paid for by the gallon. The sand shall be measured by the cubic yard and paid for under Item S-006.

Item S-005 Emulsified Asphalt Curing Membrane, per gallon

Item S-006, Aggregate (Mortar Sand)

This work consists of furnishing and placing aggregate mortar sand. The sand shall be placed at a rate as outlined in Item S-005. The sand shall conform to the standards as outlined in Section 1003.02 (a) (Mortar Sand).

Measurement and Payment: The aggregate (mortar sand) shall be measured by the cubic yard (vehicular measurement) and paid for under Item S-006.

Item S-006, Aggregate (Mortar Sand), per cubic yard (vehicular measurement)

Item S-010, Polypropylene Fiber Reinforcement: This item consists of furnishing polypropylene fiber reinforcement materials in acccordance with this specification.

Material: The fiber shall be discrete, fibrillated polypropylene as manufactured by the Synthetic Industires (Fibergrids), 4019 Industry Drive, Chattanooga, TN 37416, (800) 621-0444, or approved equal. The manufacturer shall provide a notarized certificate of compliance stating that the following average material properties are met by the supplied fibers.

Property	Test Method	Requirements
Polypropylene-$(C_3H_6)_n$	ASTM D4101 Group 1/Class 1/Grade 2	99.4%
Color	-	Black
Specific Gravity	ASTM D792	0.91
Tensile Strength	ASTM D2256	45 ksi
Ultraviolet Resistance	-	Nil
Moisture Absorption	-	0.6%
Elongation (%)	ASTM D2256	15.5
Modulus of Elasticity	ASTM D2101	700 ksi
Fiber Length	Measured	1 inch

The fibers shall be packaged in 20 lb. sealed polyethylene bags. The packaged fibers shall be stored in a manner to protect them from exposure to moisture, direct sunlight, and damage.

Measurement and Payment: Polypropylene fiber reinforcement shall be measured by the pound. The number of bags used and the weight per bag will be used for measurement. Payment for polypropylene fiber reinforcement will be made at the contract unit price per pound.

Payment will be made under:

Item S-010, Polypropylene Fiber Reinforcement, per pound.

APPENDIX 2

Moisture contents

Station	Lane	Moisture Content	Date
8+00	NB	23.6	4-21-99
8+00	SB	17.9	“
10+00	NB	22.9	“
10+00	SB	19.5	“
11+00	NB	20.0	“
11+00	SB	17.8	“
12+00	NB	26.6	“
13+00	SB	18.2	“
15+00	NB	18.0	“
16+00	NB	21.0	“
17+00	NB	22.0	“
18+00	NB	20.6	“
20+00	NB	22.0	“
23+00	NB	19.7	4-23-99
23+00	SB	24.7	“
24+00	NB	18.3	“
24+00	SB	19.5	“
25+00	NB	18.8	“
25+00	SB	22.0	“
26+00	NB	19.9	“
26+00	SB	20.1	“
27+00	SB	22.7	“
28+00	SB	22.7	“
29+00	NB	20.6	“
29+00	SB	23.0	“
29+00	SB	24.5	“
29+00	SB	21.3	“
30+00	NB	20.6	“
30+00	SB	20.7	“
31+00	SB	20.4	“
32+00	NB	19.2	“
32+00	SB	21.6	“
33+00	NB	19.1	“
33+00	SB	20.9	“
60+00	SB	18.7	“
68+00	SB	17.4	4-27-99
80+00	SB	19.0	“
86+00	SB	18.0	“
96+00	NB	207	“

APPENDIX 3

Soil Classifications

Soil (1) Classification	Test section								
	1	2	3	4	5	6	7	8	9
Sieve									
+4	0	0	0	0	0	0	0	0	0
+10	3.51	4.11	3.07	3.45	7.1	2.8	2.23	4.11	4.48
+40	9.98	8.96	11.88	12.85	9.75	8.54	9.95	11.61	12.52
+200	6.42	6.57	6.38	7.19	5.08	6.59	5.26	5.38	5.86
Silt (%)	67.76	67.89	67.04	66.37	67.62	70.65	70.58	67.38	66.39
Clay(%)	12.02	12.47	11.63	10.14	10.45	11.42	11.98	11.51	10.75
LL	30	31	33.5	32	32.5	37.6	36	31	29
PL	26	27	24.8	28	28.3	24.8	25	22	25
PI	4	4	9	4	4	13	11	9	4
Max Den. (2) Lbs/cu.ft.	100.2	98.9	97.3	97.0	101.0	97.3	100.4	100.8	98.0
Opt. MC (%) (2)	21.8	24.2	23.2	20.0	21.0	23.5	21.3	21.5	22.6
Soil Class (1)	A-4	A-4	A-4	A-4	A-4	A-4	A-4	A-4	A-4

(1) This material is a recycled soil cement base course whose classification resembles the soil class indicated

(2) These results were taken from the field moisture density tests conducted by DOTD construction technicians.