TECHNICAL REPORT STANDARD PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/LA.97/303		

4. Title and Subtitle Field and Lab Evaluation of the Use of Lime/Fly Ash to Replace Soil Cement Stabilized Base Course	5. Report Date September 1997 6. Performing Organization Code
7. Author(s) Hadi Shirazi and Ken Johnston	8. Performing Organization Report No. 303
9. Performing Organization Name and Address Louisiana Transportation Research Center 4101 Gourrier Avenue Baton Rouge, LA 70808	10. Work Unit No. Study No. LA-SPR-91-5GT 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Louisiana Transportation Research Center 4101 Gourrier Avenue Baton Rouge, LA 70808	13. Type of Report and Period Covered Final Report 04/01/91 - 06/30/96 14. Sponsoring Agency Code

15. Supplementary Notes

Conducted in Cooperation with the U.S. Department of Transporation, Federal Highway Administration

16. Abstract

This study evaluates the performance of lime/fly ash stabilized base as an alternate to soil cement stabilized base for flexible pavement systems on reconstructed Louisiana highways. Louisiana has historically used soil cement for most flexible base construction due to its low cost, high compressive strength, and ease of construction. However, soil cement is subject to excessive cracking due to shrinkage, which may decrease the expected pavement life. Lime/fly ash bases exhibit many of the same properties as soil cement bases with potential for less shrinkage cracking.

Lime/fly ash (Class C fly ash) test sections were installed on two Louisiana highway reconstruction projects, located in the northwestern part of the state. For each project, two 0.4 km (0.25 mile) test sections using different percentages of lime and fly ash were constructed. The remainder of each project was constructed using 8 percent soil cement base by volume. For both projects, the first test section used 2 percent lime/4 percent fly ash by weight for stabilization and the second test section used 3 percent lime/6 percent fly ash.

Test specimens were molded in the field during construction using stabilized base material taken from the roadway immediately prior to compaction. Laboratory test specimens were made later using materials taken from, but not mixed at, the construction sites. Both field and laboratory samples were tested in unconfined compression at 7, 28 and 56 days. The overall unconfined compressive strength of lime/fly ash was 30 percent lower than that of soil cement.

After the reconstruction was completed, monitoring strips were marked to indicate test sections and control sections for both highways. Crack mapping and Dynaflect readings were taken periodically for five years. Rut depth measurements were taken at five years. The lime/fly ash section showed less cracking than the soil cement section. The cracks were 52 linear feet per 100 foot test lane for 2 percent lime/4 percent ash, 81 linear feet per 100 foot test lane for 3 percent lime/6 percent fly ash, and 403 linear feet per 100 foot test lane of 8 percent soil cement by volume, respectively. The overall average of structural numbers determined from Dynaflect were 3.4 for soil cement and 4.5 for lime/fly ash mixture. The subgrade modulus was lower for lime/fly ash by 2000 psi.

Testing and monitoring results are presented. Recommendations concerning the use of lime/fly ash as a substitute for soil cement base are made based on the test section performance.

17. Key Words	18. Distribution Statement
Lime/fly ash, soil cement stabilizer base course, cracking, Dynaflect structural number and subgrade modulus	Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

Field and Lab Evaluation of the Use of Lime Fly Ash to Replace Soil Cement as a Base Course

Final Report by

Hadi Shirazi
Ken Johnston

LTRC REPORT NO. 303
LTRC PROJECT NO. 91-5GT(B)
STATE PROJECT NO. 736-16-0052

conducted for

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
LOUISIANA TRANSPORTATION RESEARCH CENTER

September 1997

ABSTRACT

This study evaluates the performance of lime/fly ash stabilized base as an alternative to soil cement stabilized base for flexible pavement systems on reconstructed Louisiana highways. Louisiana has historically used soil cement for most flexible base construction due to its low cost, high compressive strength, and ease of construction. However, soil cement is subject to excessive cracking due to shrinkage, which may decrease the expected pavement life. Lime/fly ash bases exhibit many of the same properties as soil cement bases with potential for less shrinkage cracking.

Lime/fly ash (Class C fly ash) test sections were installed on two Louisiana highway reconstruction projects, located in the northwestern part of the state. For or within each project, two 0.4 kilometer (km) (0.25 mile) test sections using different percentages of lime and fly ash were constructed. The remainder of each project was constructed using 8 percent soil cement base by volume. On both projects, the first test section used 2 percent lime/4 percent fly ash by weight for stabilization and the second test section used 3 percent lime/6 percent fly ash.

Test specimens were molded in the field during construction using stabilized base material taken from the roadway immediately prior to compaction. Laboratory test specimens were made later using materials taken from, but not mixed at, the construction sites. Both field and laboratory samples were tested in unconfined compression at 7, 28, and 56 days. The overall unconfined compressive strength of lime/fly ash was 30 percent lower than that of soil cement.

After the reconstruction was completed, monitoring strips were marked to indicate test sections and control sections for both highways. Crack mapping and Dynaflect readings were taken periodically for five years. Rut depth measurements were taken at five years. The lime/fly ash section showed less cracking than the soil cement section. The cracks were 52 linear feet per 100 foot test lane for 2 percent lime/4 percent fly ash, 81 linear feet per 100 foot test lane for 3 percent lime/ 6 percent fly ash, and 403 linear feet per 100 foot test lane of 8 percent soil cement by volume, respectively. The overall average of structural numbers determined from Dynaflect were 3.9 for soil cement and 4.0 for lime/fly ash mixture. The subgrade modulus was lower for lime/fly ash by 2,000 psi.

Testing and monitoring results are presented. Recommendations concerning the use of lime/fly ash as a substitute for soil cement base are made based on the test section performance.

ACKNOWLEDGMENTS

John Oglesby was the initial principal investigator of the study for five years. He has worked on most of the study and data calculation. He completed the project by May 1996 before he transferred to DOTD headquarters, Contract Management. The co-principal investigators, Hadi Shirazi and Ken Johnston, completed the written part of the study.

Special thanks to Mark Morvant who helped us edit and organize this report.

The Dynaflect testing conducted in this study was provided through the Pavement Management Group of Louisiana Transportation Research Center by Masood Rasoulian, Gary Keel, and Alvin Mix.

Paul Brady, Tim Taylor, Melba Bounds, Alfred Moore, Chad Penn, Damian Law, Anthony Beard, Shannon Thibodeaux, Coy Purkey, and Nicole Harper provided the laboratory testing and scaled drawings of the crack maps.

Special thanks to Ron Watts who helped us gather information on other lime/fly ash construction and rehabilitation projects.

IMPLEMENTATION STATEMENT

This project accomplished satisfactory results which increased confidence in the use of lime/fly ash as an alternate to cement stabilized base. Lime/fly ash showed better characteristics in lieu of soil cement stabilized base. The lime/fly ash exhibited much less cracking than the soil cement stabilized base. Even though lime/fly ash has lower unconfined compression strength than soil cement stabilized base, the long term performance of the pavement was not adversely affected. In one location lime/fly ash was placed in a low vertical curve with high moisture. There were no visibility of cracking in the particular location, however, the dynaflect readings decreased with time.

Based on the performance of these test sections, LTRC recommends continued use of lime/fly ash stabilized bases on low volume roads in areas of low water table.

Extensive use of lime/fly ash bases should be limited to the northern half of Louisiana. Use in the southern part of the state should be considered on a case by case basis when subsoil conditions allow.

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INTRODUCTION

Louisiana has a long history of using soil cement as a base material for highways. Soil cement bases are economical, attain high compressive strengths and are relatively easy to design and construct. A wide variety of soil types can be successfully used to make soil cement, making it a versatile material. When soil cement base is properly constructed as a part of a well designed flexible pavement system, excellent results are obtained.

Unfortunately, soil cement has some disadvantages. Cracking caused by shrinkage and nonuniform mixture are the most obvious and the most often cited. This usually results in uniformly spaced transverse cracks which may reflect up through the asphalt surfacing. Whether this is a structural problem or merely an aesthetic one it is open for debate. Factors such as crack width and water infiltration can cause stripping of hot mix, weakening of base, and pumping of the subgrade layer. The amount of cement added is often much greater than necessary to obtain design compressive strength, therefore creating a greater potential for more cracking.

In the late 1980's, Louisiana highway officials in the northwest (Shreveport) district noticed that pavements constructed using lime/fly ash bases in the adjacent Texas highway district west of Shreveport were in excellent condition while similar pavements constructed with soil cement bases in Louisiana were cracked and required maintenance. The two districts share similar geographical characteristics and construction techniques. The main difference was in the materials used in construction of the base. Test sections using Texas specifications for lime/fly ash base were requested. An LTRC research proposal was drafted to evaluate lime/ fly ash as an alternate to soil cement base.

Originally, LTRC researchers hoped to install test sections on new roadways. This would have allowed adequate time to custom design a lime/fly ash test section for the specific base soil to be used on each project using Texas laboratory evaluation procedures. However, most of the scheduled work in the northwest district and throughout the state was reconstruction of existing roadways. Louisiana's highway infrastructure is reasonably well established, and in the foreseeable future, most construction will be to update and upgrade the existing highway system. For this reason, sections of two existing state highways scheduled for reconstruction were selected for installation of test sections. Both highways had soil cement bases which would be pulverized and treated to form the new base.

OBJECTIVE

The purpose of this project was to design and construct lime/fly ash stabilized base course test sections which would be economical compared to a soil cement stabilized base, utilize a recyclable material, and possibly reduce shrinkage cracking on bases and the subsequent reflective cracking of the riding surface. Satisfactory results from this project would increase confidence in the use of lime/fly ash as an alternate to cement stabilized treated base: thus resulting in greater utilization of lime/fly ash for base stabilization. Factors such as a crack mapping procedure, durability comparison between lime/fly ash and soil cement stabilized base and structural number determination for lime/fly ash bases were studied.

Because of the time constraints for a laboratory program before construction, Texas' construction specifications for the lime/fly ash test sections were used. Each test section would be 0.4 km(0.25 miles) long and use different percentages of lime and fly ash. Due to time constraints , the two most common treatments of lime/fly ash used in Texas were selected: two percent lime/four percent fly ash, and three percent lime/six percent fly ash. The construction process was monitored closely to insure conformance with the specifications chosen for the project. Test specimens were molded in the field during construction utilizing blended base material prior to compaction. Laboratory test specimens were made later from materials taken from, but not mixed, at the test sites. Comparison tests were run using laboratory samples at 7, 28, and 56 days.

SCOPE OF RESEARCH

Upon completion of construction, monitoring strips were placed on the lime/fly ash pavement test sections as well as adjacent to the soil cement control sections on both projects. The reconstructed pavements were monitored for five years. The monitoring primarily consisted of crack mapping, Dynaflect readings and rutting depth of pavement sections. Also, this study compared lab and field results to determine if the laboratory design was accurate.

Research was limited to evaluation of reconstructed bases. Old pavement and cement treated base was used as the construction material to be treated using lime/fly ash or cement. No evaluation of lime/fly ash as an alternative to soil cement base treatment in raw soil was performed.

The evaluated reconstruction work was on rural, low volume state highways. No evaluation of high volume pavement performance was made.

METHODOLOGY

PROJECT SELECTION AND CONSTRUCTION

Two projects were chosen for test sections in North Louisiana: State Project Number (SPN.) 088-03-08 on LA 507 north from Castor to the junction of LA 154 located in Bienville parish and SPN. 109-03-04 on LA 518 north from Aycock to Lisbon located in Claiborne parish. Both highways had soil cement stabilized bases which would be pulverized and treated to form new bases. All information is shown in Table 1.

Table 1
Project Summary Description

	LA 507 SPN 088-03-0008	LA 518 SPN 109-03-0004
Annual Daily Traffic (ADT) 1990	18% truck, 10% RV 540	23% truck, 12 % RV 780
length	0.4 km(0.25 miles)	0.4 km(0.25 miles)
Primary Base Soil Type	A-2-4/silty or clayey gravel and sand	A-2-4/silty or clayey gravel and sand
Control Section	Soil Cement, 8% by vol.	Soil Cement, 8% by vol
Lime/Fly Ash test section	250 mm (10") thick 2% lime/4% fly ash 250 mm (10") thick 3% lime/6% fly ash	250 mm (10") thick 2% lime/4% fly ash 250 mm (10") thick 3% lime/6% fly ash

Prior to mixing of materials the pulverized base was shaped to conform to the typical sections as directed by the project engineer. The base material was thoroughly pulverized before blending operations were allowed to start. Base material was pulverized until at least 60 percent passed a No. 4 sieve. Lime was spread only on an area where mixing could be completed during the same working day. Mixing continued until, in the opinion of the Engineer, a homogenous, friable mixture of material and lime was obtained, free from all clods or lumps. Fly ash application began after the lime modified base material had passed the above mentioned grading requirements and had cured for a minimum of three days.

Compaction of the mixture began immediately after the fly ash was added and thoroughly mixed. The contractor was required to attain at least 95 percent of maximum dry density within 6 hours. The material was sprinkled with water as necessary to maintain optimum moisture and brought to the required lines and grades in accordance with the existing typical sections by tight blading.

After the lime/fly ash treated base course was finished, the surface was protected against rapid drying for a period of at least three days before the surface course was placed. The protection mechanism was an asphaltic membrane applied directly to the treated base course in sufficient quantity to completely cover and seal the total surface of the base.

Specifications for construction of lime/fly ash reconstructed base test sections were based on Texas specifications. The specifications were modified only in regard to site location and project limits. Both projects included two 0.4 km (0.25 mile) test sections, one for each lime/fly ash percentage combination selected. The rest of each project, approximately 12 km each, used soil cement base at 8% cement by volume. The lime/fly ash bases were 250 mm (10 in.) thick, as compared to the soil cement base sections, which were 215 mm (8.5 in.) thick.

Field samples

Field cylinders for unconfined compression testing were fabricated according to the molding procedure described in DOTD TR 434-81. A sample weighing approximately 13 kg (30 pounds) was taken from the roadway after blending was completed prior to compaction. The + 4 material was removed and a moisture sample was taken prior to molding. Molds used were 101.6 mm (4 in.) in diameter and 116.43 mm (4.584 in.) in height. The compaction device was a sliding weight hammer weighing 2.5 kg (5.5 lbs.) with a 304.8 mm (12 in.) drop. Samples were fabricated on a molding block. An effort was made to find a location in the shade for molding to prevent evaporation and retard setting of the stabilizing agents. The soil mixture was compacted in three layers at twenty-five blows per layer, with scarification between the layers. After molding, the sample was trimmed even with the top of the mold, a plastic bag was placed over the top of the sample, and the collar of the mold was reattached to secure the bag and act as a moisture barrier. This procedure was repeated as long as construction continued on the control and test sections in order to obtain a maximum number of samples to determine unconfined compressive strength. The molded samples were then sealed in plastic bags and transported to the LTRC soils laboratory in Baton Rouge for testing. The molded samples were weighed in molds for density determination and then extruded, bagged and placed in a 100 percent humidity room to cure for the specified time. Cure times were 7, 28, and 56 days for the LA 518 sections. The LA 507 cure times were 7 and 28 days for the soil cement section; and 7, 14, 28, and 56 days for lime/fly ash sections. Specimens were fabricated to provide unconfined compressive strength data for both lime/fly ash base mixes and for the soil cement base mix. It is important to note that the field samples were allowed to remain in the molds for up to 48 hours after fabrication before extrusion and placement in a humidity room. The field samples were also exposed to temperatures representative of late spring in the interior of an open automobile in Louisiana.

Laboratory samples

Lime, fly ash, cement, and raw base material was sampled from the project sites during construction and brought to LTRC for laboratory testing. Under laboratory conditions, samples were molded using the same percentage of stabilizing materials as reported during construction. Sand/clay/gravel base from LA 518 was used to fabricate lab molded cylinders. Samples were cured and tested in accordance with unconfined compression results(presented in Appendix A) at the same time intervals that were used for the field test specimens.

Crack mapping

After the asphaltic surfacing was in place, three 30 m (100 ft) monitoring strips were marked on the surface of each lime/fly ash test section and on an adjacent control section of soil cement base. A total of eighteen monitoring strips were marked on the two projects.

Crack surveys were taken concurrently with pavement evaluation using the Dynaflect during the following months: November 1991, May 1992, February 1993, December 1993, January 1995 and January 1996.

The 30 m (100 foot) lanes were drawn to scale on graph paper with three lanes per sheet. Each sheet represented the monitoring strips in a test or control section. Starting several months after construction was completed, each monitoring strip was walked and the cracks were recorded on the graph paper. Crack mapping was then done every six to twelve months over a five year period. Black and white copies, showing all cracks to date, were made after each mapping. The original sheets were used each time in the field, with a different color pencil used to show the progressive cracking.

The survey sheets are reproduced in APPENDIX B and provide a graphic means of comparing the cracking in the lime/fly ash with the Soil Cement control sections.

Dynaflect

The Dynaflect is a non-destructive test which measures the amount of deflection created by an applied load. It's an electro-mechanical system consisting of a dynamic force generator and a motion measuring system which is mounted on a towed trailer with a number of suspended motion sensing geophones. The generator is able to produce a vertical force, at the rate of eight cycles per second, that is projected onto the pavement through a pair of rigid steel wheels. The force applied consists of the static load of the instrument trailer (amount of load) in addition to the dynamic force which alternately adds to and subtracts from the static load of the trailer. The peak to peak excursion of the dynamic force is 4.4 KN (1000 lbf) The pavement deflects downward, and the amplitude of the vertical motion is sensed by the geophones, which are in contact with the pavement at specific distances along the length of the trailer tow bar.

When evaluating Dynaflect measurements, the maximum average deflection should be taken as being indicative of pavement performance. The shape of the curve obtained from the Dynaflect data can help in projecting pavement performance. Dynaflect readings were taken each time crack mapping was performed. The first set of Dynaflect readings were taken directly on the new base layers (see appendix C for test results).

Rut depth measurements

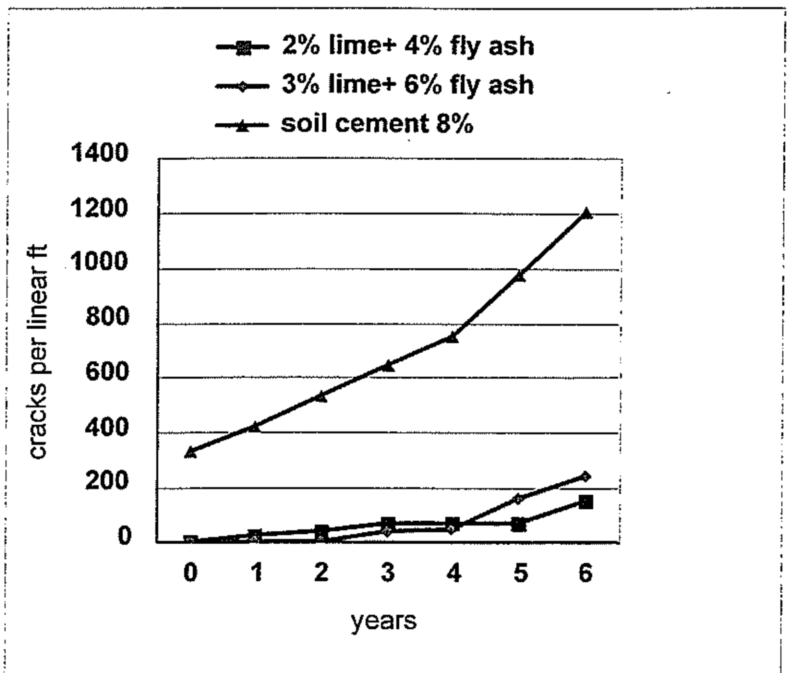
Part of the monitoring plan during the research project was the collection of rutting measurements from the test lanes. Since visible rutting never occurred in any test or control section, rutting depth measurements were only taken once, in January, 1996. (See the discussion section of this report for rutting analysis). All rut depth measurements were taken from the outer wheel path. The corner of the measuring device was always placed on the inside edge of the painted shoulder stripe to insure uniformity.

DISCUSSION OF RESULTS

Crack maps

The soil cement stabilized base control sections on both LA 518 and LA 507 exhibited more cracking than the lime fly ash sections. See APPENDIX B for a visual representation of crack propagation in the monitored sections. The difference in cracking between 2% lime / 4% fly ash and 3% lime / 60% fly ash was not significant. The total transverse and longitudinal wheel path cracks for 2% lime/4% fly ash were 48 m (157 linear feet), and 75 m (244 linear feet) for 3% lime / 6% fly ash. The 8% cement stabilized section fly ash had a total of 369 m (1211 linear feet) of transverse and longitudinal wheel path cracks. Figure 1 presents a graph showing the difference in cracking between lime/fly ash and soil cement stabilized bases.

Figure 1



Field and lab cylinder comparison results

Figure 2 presents results of strength gain verses time as determined by unconfined compression tests on lab molded samples of LA 518. Figure 3 presents strength gain verses time on field molded samples from LA 518 and LA 507. Soil cement stabilized field specimens did achieve and exceed the required strength of 1.72 Mpa (250 psi) after a cure of 7 days. The lime/fly ash treated material did not achieve the high strengths attained by the stabilized soil cement. Laboratory specimens yielded test results that exhibited the same general trends of unconfined compressive strength as did the field molded samples.

Dynaflect

Dynaflect tests were run on all base courses before and after asphalt surfacing was placed. Test sections stabilized with lime/fly ash experienced initial increases in structural numbers and stiffness similar to the control sections stabilized with cement. After five years of service both the lime/fly ash and cement stabilized test sections showed similar final in structural number stiffness as shown in Table 2. A complete list of structural numbers and subgrade modulus results are presented in appendix C.

Table 2

Dynaflect structural numbers after five years

Sites	Soil Cement	3% lime/ 6% fly ash	2% lime/ 4% fly ash
LA 518	4.1	3.2	4.1
LA 507	3.6	4.6	3.8

Figure 4 presents the structural number verses time for LA 507. The structural numbers for the soil cement base were consistently lower than both the lime/fly ash bases. Figure 5 presents the structural number verses time for LA 518. The 3% + 6% lime fly ash exhibited lower structural number than the soil cement and 2% + 4% lime/fly ash base. This may be attributed to the location of the 3% + 6% section, built in the bottom of a vertical curve, the higher moisture content of the subgrade may have reduced the structural numbers.

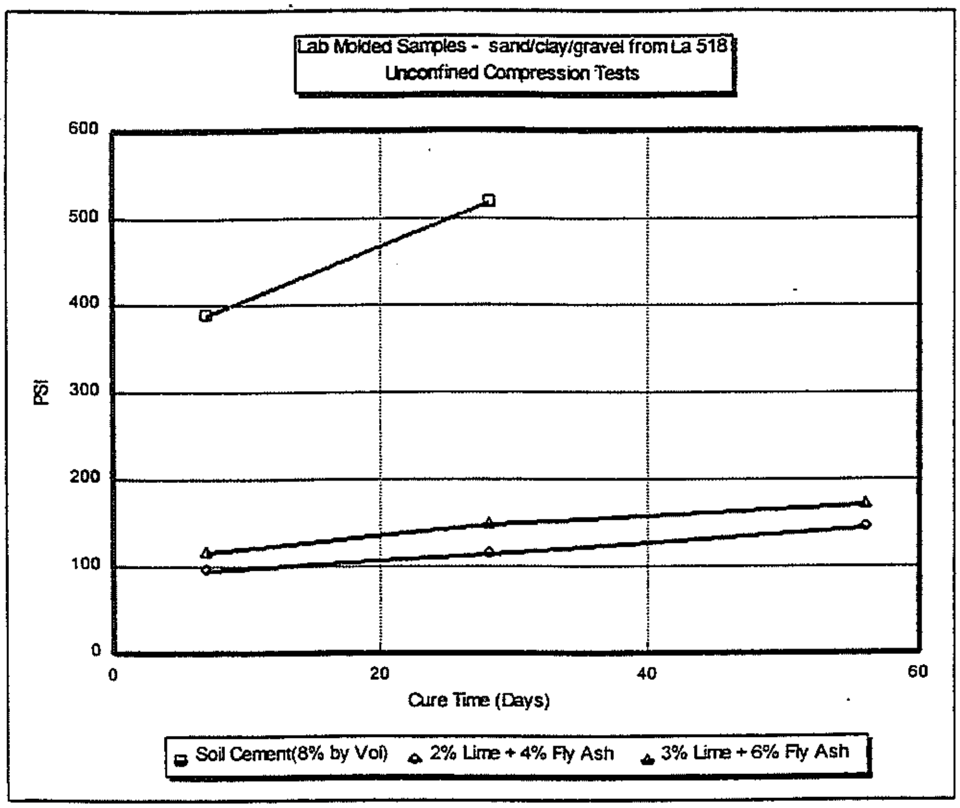
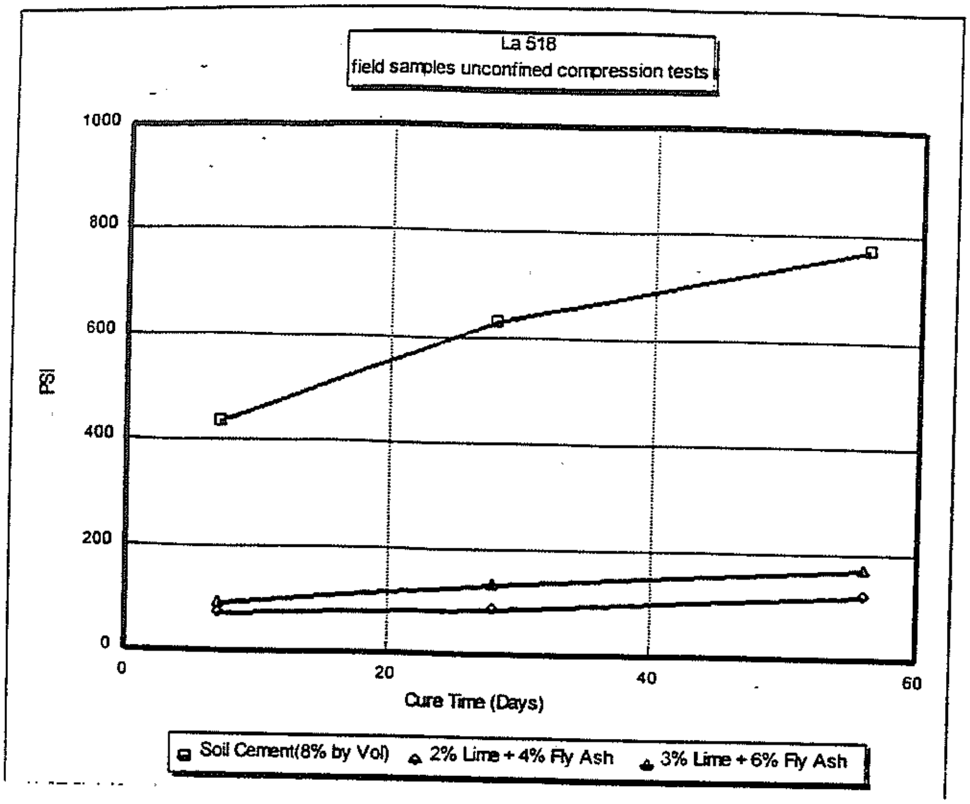


Figure 2
Field and Laboratory unconfined compression results



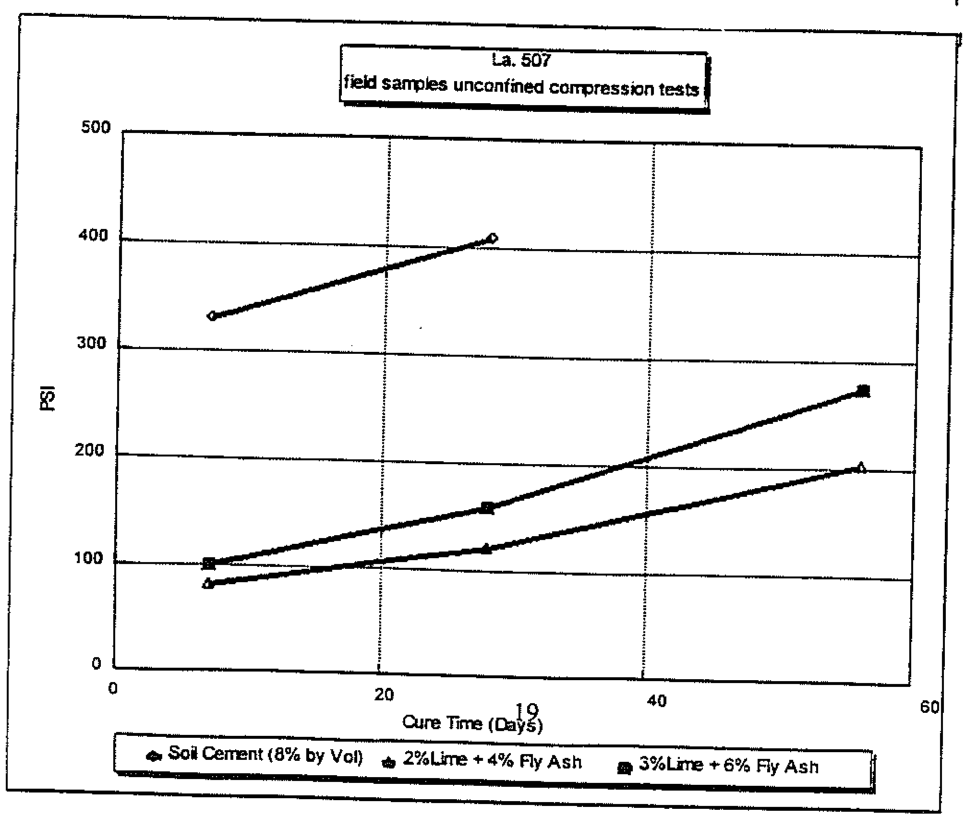


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Figure 3
Field and Laboratory unconfined compression results

Figure 4

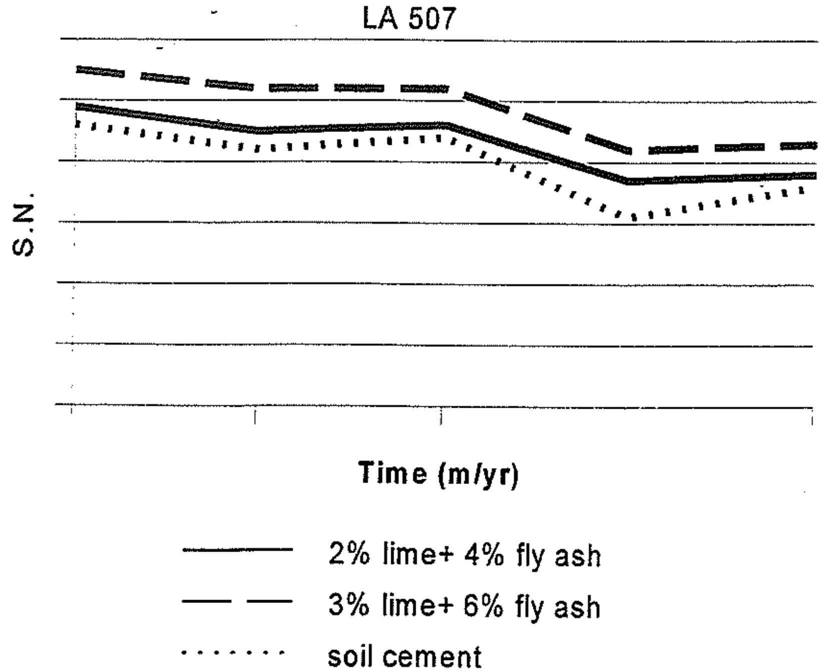
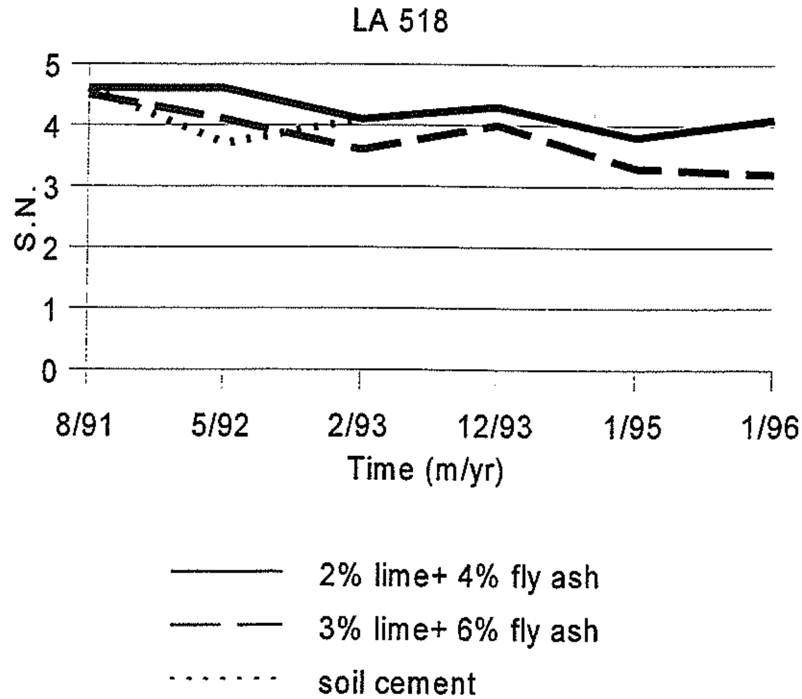


Figure 5



Structural number vs. time

After five years of service both the lime/fly ash and cement stabilized test sections showed similar final in subgrade modulus stiffness as shown in Table 3. The subgrade modulus was calculated from the " Pavement Evaluation Chart for Dynaflect" readings verses percent spread surface. This chart is available from the LTRC Pavement Management Group. The pavement evaluation chart divides a pavement section into two strengths: relative subgrade strength or subgrade modulus (Es) and total pavement strength or structural number (SN). Tests on a given pavement at two points in time can provide the means to determine whether the subgrade layers, the pavement layers, or both have changed in relative strength. Figure 5, and Figure 6 show the subgrade moduli for LA 518 and LA 507.

Table 3

Dynaflect subgrade modulus after five years

Sites	Soil Cement	3% lime/ 6% fly ash	2% lime/ 4% fly ash
LA 518	16,200	15,100	13,840
LA 507	8,142	6,509	6,060

Rutting depth

Rutting never became obvious during the five year monitoring period, thus measurements were not taken until the final site evaluation. Rutting was not significant in either LA 518 or LA 507.

Economic analysis

The economic analysis was done using the latest "Weighted Averages" summary published quarterly by the DOTD and the tabulation of low bidder for the two projects mentioned above. The analysis shows that lime/fly ash can be a viable alternative to soil cement. The material cost per linear foot was $5.53 for soil cement, $2.12 for lime, and $1.42 for fly ash. This analysis was based on the placement cost in the original contract price, and may vary in other applications. The placement cost for soil cement 216 mm(8.5") thick is $2.20 per square yard and$2.50 per square yard for lime/fly ash 250 mm (10") thick. See appendix D, for further explanation of this data.

A contributing factor to an economic analysis is the fact that lime/fly ash has to be placed as two separate operations. After the lime is cut into the soil, it must cure for 72 hours before the fly ash can be added and mixed. This effectively increases the "placement" cost as compared to soil cement. On a large project, the 72 hour curing time would not be an added cost, but on a smaller project this could cause delays for the contractor.

Figure 6

LA 518

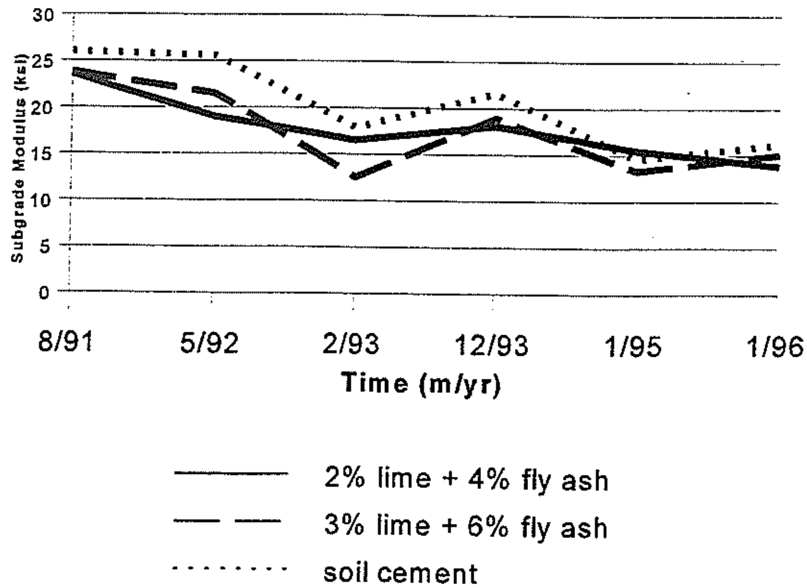
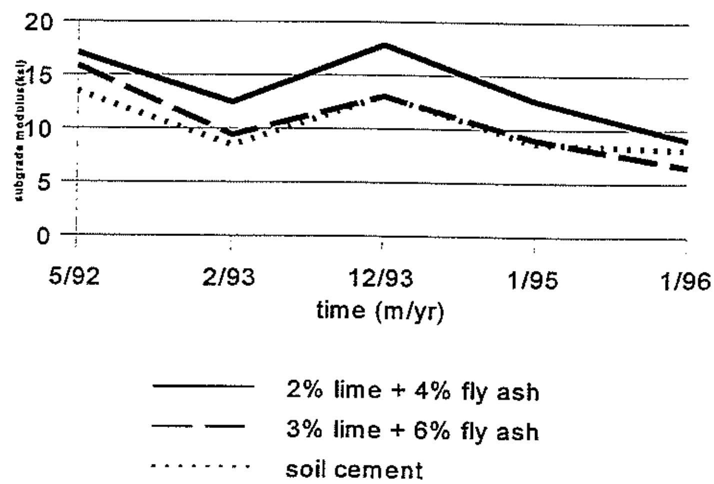


Figure 7

LA 507



Subgrade modulus (ksi) vs. time

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The soil cement stabilized control sections cracked earlier and more extensively than the lime/fly ash test sections. Results indicate that lime/fly ash is less prone to shrinkage than the soil cement stabilized base.

Both percentage selections of lime/ fly ash did comparably well. Based on visual observation of the crack maps (see appendix B), the 2 percent lime/4 percent fly ash did better on one project than the 3 percent lime/6 percent fly ash, yet, it did worse on the other.

Dynaflect results for the test lanes and control sections on both LA 518 and LA 507 have generally decreased over five years of monitoring.

It was determined that no significant rutting occurred in any of the test or control section monitoring strips.

The unconfined compression strengths of the lime/fly ash bases were much lower than soil cement bases. This fact did not results in reduced structural numbers or long term performance.

None of the test or control sections have showed any noticeable deterioration. Although cracking ranges from almost non-existent in some test section's monitoring strips to fairly heavy in other control section monitoring strips, road quality and "rideability" are still excellent.

Recommendations

Based on the results of this study, lime/fly ash should be considered for use as an alternate for soil cement 1) where it is more cost effective and 2) where it is important to reduce surface cracking. This study was limited to reconstruction usage of lime/fly ash on rural, low volume roads. More research should be considered using lime/fly stabilization on reconstruction projects with different types of base material. Monitoring of the test sections on LA 518 and LA 507 should be continued on an annual basis. Evaluation of the performance of the projects mentioned in the "Implementation Statement" on page iii of this report should be considered. Since this study was initiated, several types of synthetic base reinforcement have become available, including composite bases using lime/fly ash stabilization and synthetic reinforcement. These new methods of stabilization and reinforcement should be evaluated through research-oriented testing.

Appendix A
Unconfined compression test data

Unconfined Compressive Strength Data			
LA 507 - Field molded cylinders (Avg. 3 tests minimum)			
	7 day (psi)	28 day(psi)	56 day(psi)
soil cement	330	410	
2% lime + 4% fly ash	81	120	202
3% lime + 6% fly ash	99	158	274
LA 518 - Field molded cylinders (Avg. 3 tests minimum)			
soil cement	436	629	771
2% lime + 4% fly ash	74	85	122
3% lime + 6% fly ash	92	134	172
Lab molded cylinders using sand/clay/gravel from LA 518			
soil cement	389	518	
2% lime + 4% fly ash	96	116	146
3% lime + 6% fly ash	117	149	172

Note

The molded cylinders that were molded in the field were left in the mold for transportation from the jobsite to LTRC. A plastic sheet was clamped between the mold collar and the mold to minimize loss of moisture. The time between molding and extrusion of the cylinder was between 24 and 48 hours. The molds were stored and transported in a DOTD carryall. The temperature during the time of construction reached highs in the low to mid 90's. These factors should be considered when comparing cylinder strength of field molded vs. molded cylinders.

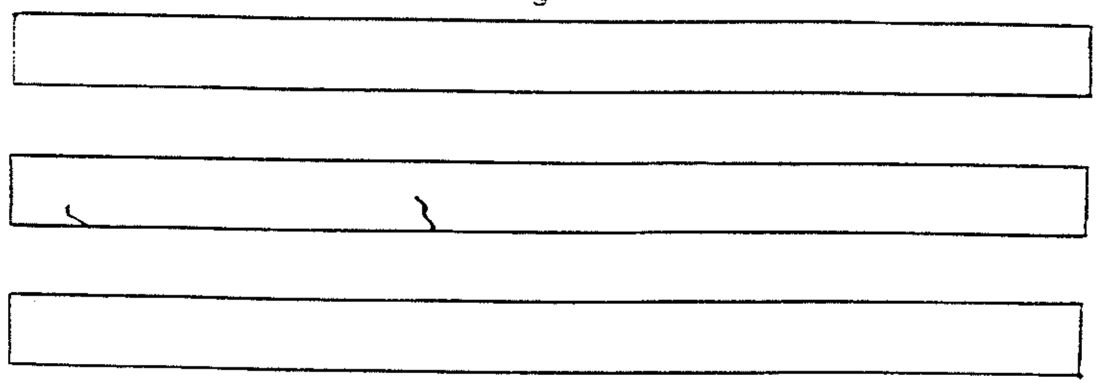
Appendix B
Crack Mapping

LA 518						
History of Crack Propagation (Linear Feet)						
Date of Survey	2% Lime + 4% Fly ash		3% Lime + 6% Fly ash		Soil Cement (8%)	
	per survey	cumulative	per survey	cumulative	per survey	cumulative
Nov 1991	0	0	0	0	333	333
May 1992	25	25	0	0	87	420
Oct 1992	13	38	0	0	115	535
Feb 1993	32	70	42	42	110	645
Dec 1993	0	70	4	46	108	753
Jan 1995	0	70	118	164	221	974
Jan 1996	87	157	80	244	237	1211
Total	157		244		1211	
Average Linear Feet per 100 ft Test Lane						
	52		81		403	

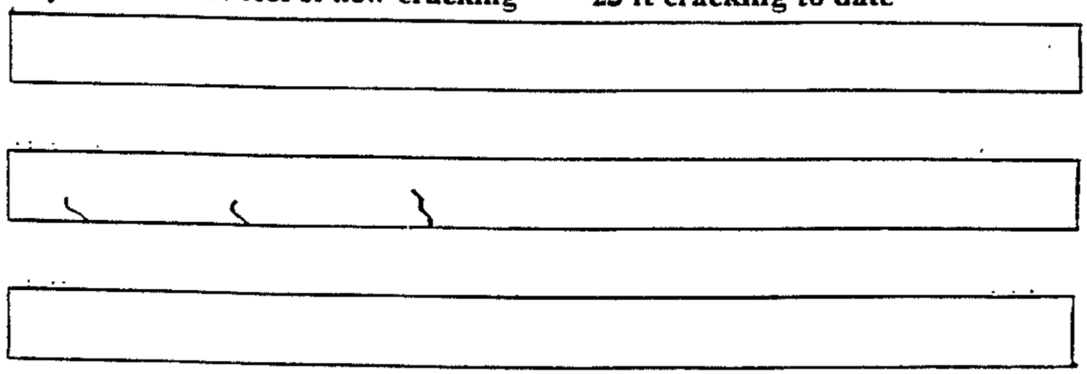
LA 507						
History of Crack Propagation (Linear Feet)						
Date of Survey	2% Lime + 4% Fly ash		3% Lime + 6% Fly ash		Soil Cement (8%)	
	per survey	cumulative	per survey	cumulative	per survey	cumulative
Nov 1991	0	0	16	16	192	192
May 1992	0	0	108	124	119	311
Oct 1992	70	70	94	218	343	654
Feb 1993	0	0	0	218	168	822
Dec 1993	50	120	88	306	107	929
Jan 1995	0	0	78	384	169	1098
Jan 1996	25	145	318	702	221	1319
Total	145		702		1319	
Average Linear Feet per 100 ft Test Lane						
	49		234		439	

La 507 Crack Survey - 3% Lime + 6% Fly Ash (Page 1 of 2)

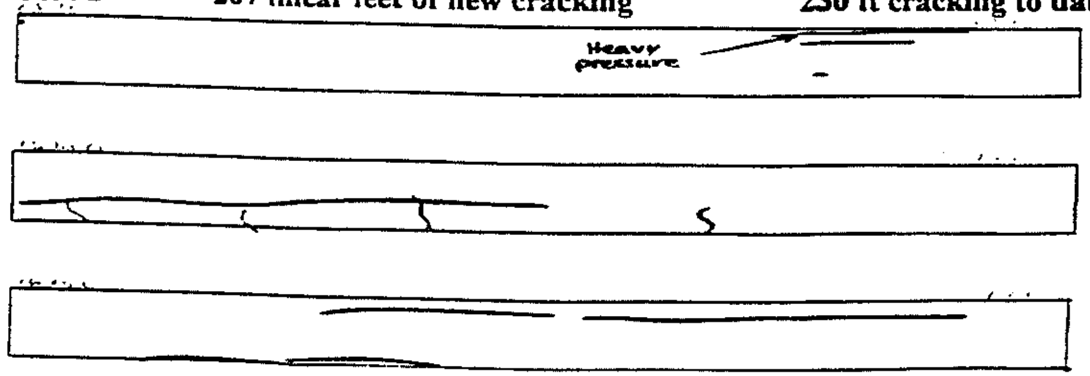
Nov 91 — 13 linear feet of cracking



May 92 — 10 feet of new cracking — 23 ft cracking to date

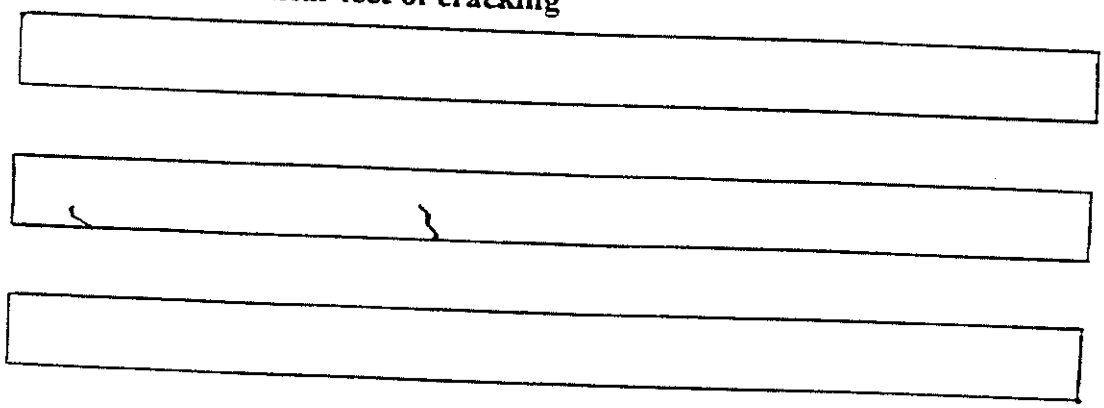


Oct 92 — 207 linear feet of new cracking — 230 ft cracking to date

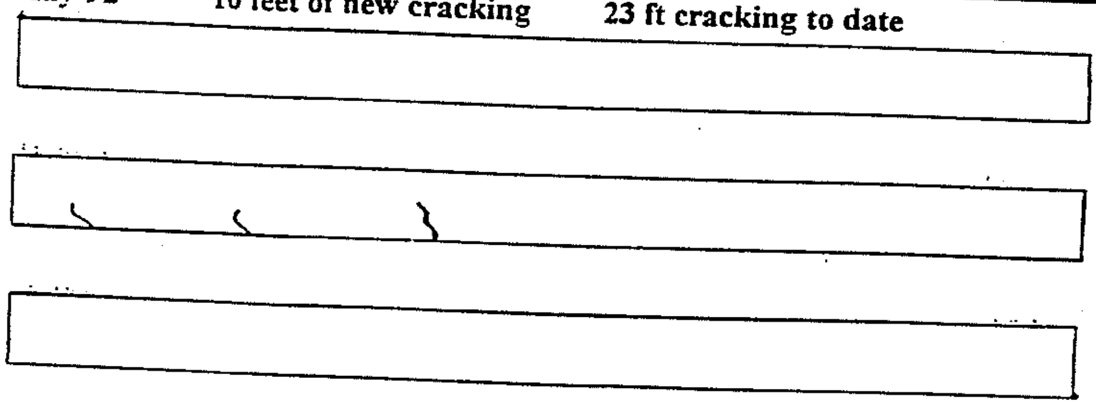


La 507 Crack Survey - 3% Lime + 6% Fly Ash (Page 1 of 2)

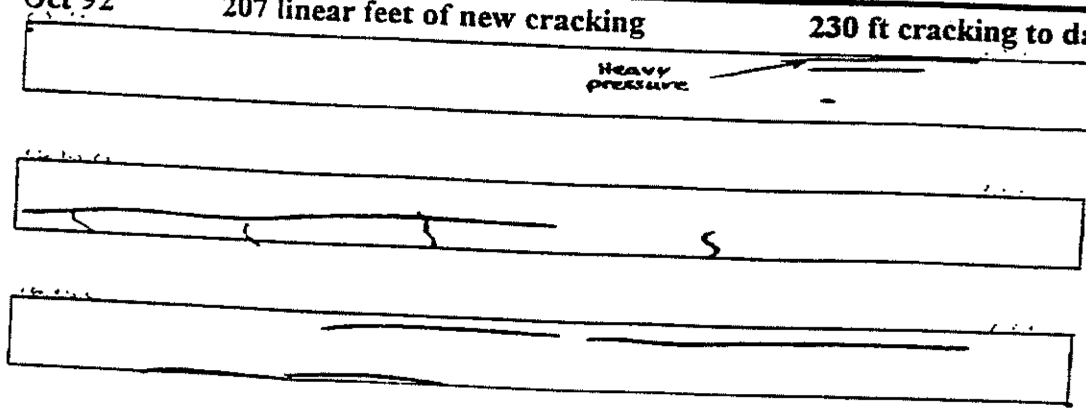
Nov 91 13 linear feet of cracking



May 92 10 feet of new cracking 23 ft cracking to date

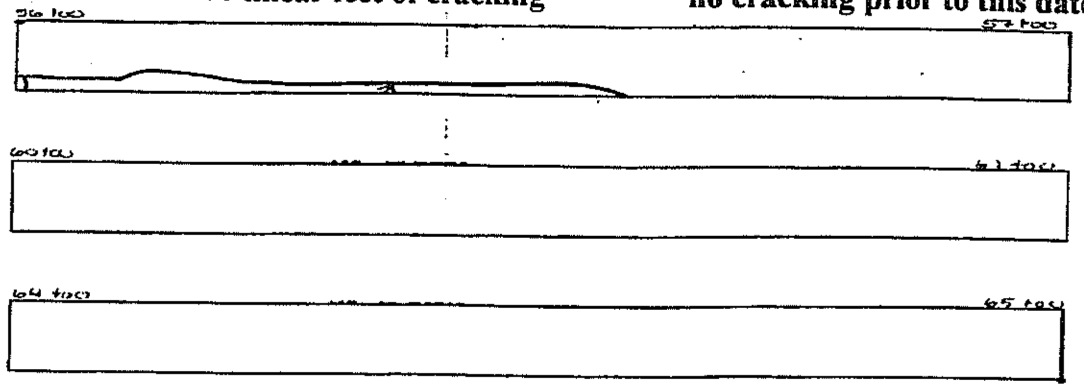


Oct 92 207 linear feet of new cracking 230 ft cracking to date

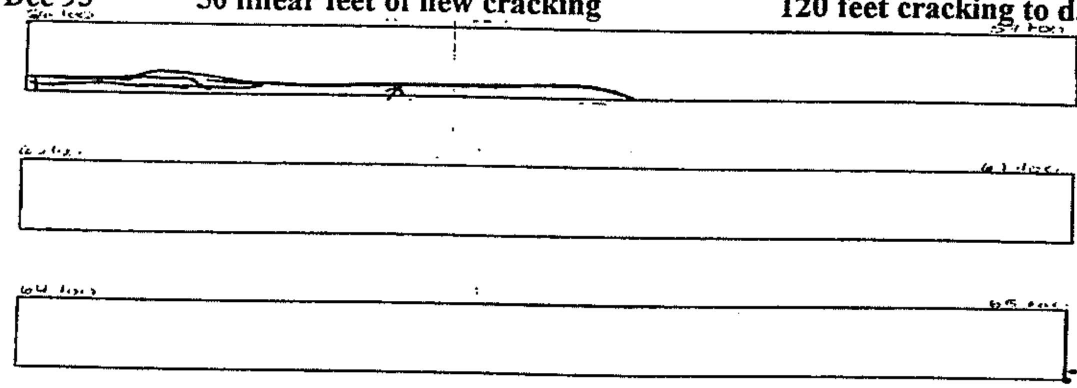


La 507 Crack Survey - 2% Lime + 4% Fly Ash

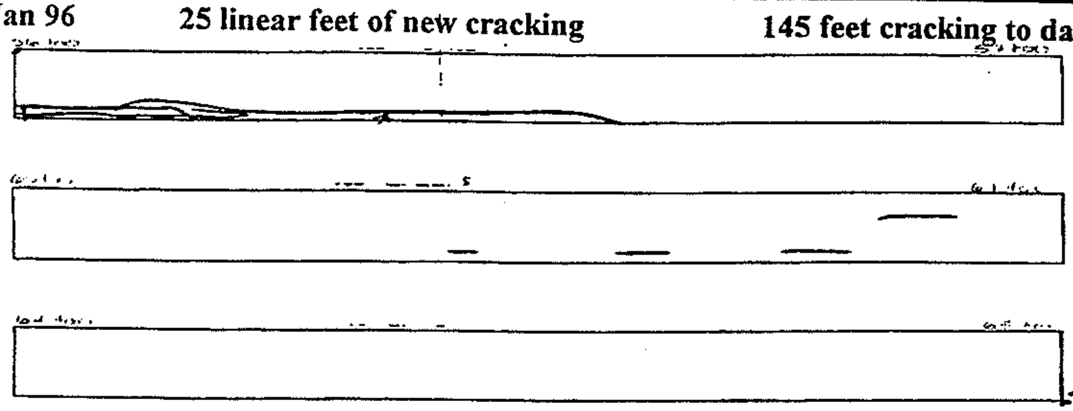
Oct 92 — **70 linear feet of cracking** — **no cracking prior to this date**



Dec 93 — **50 linear feet of new cracking** — **120 feet cracking to date**

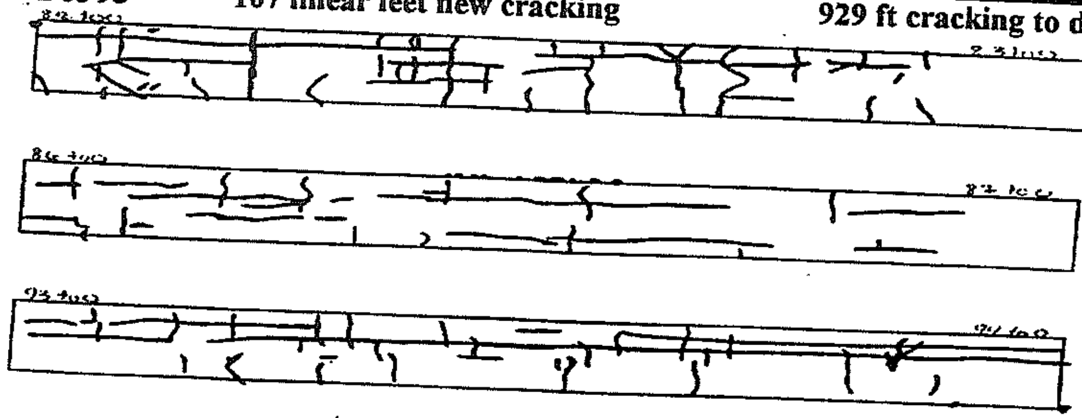


Jan 96 — **25 linear feet of new cracking** — **145 feet cracking to date**

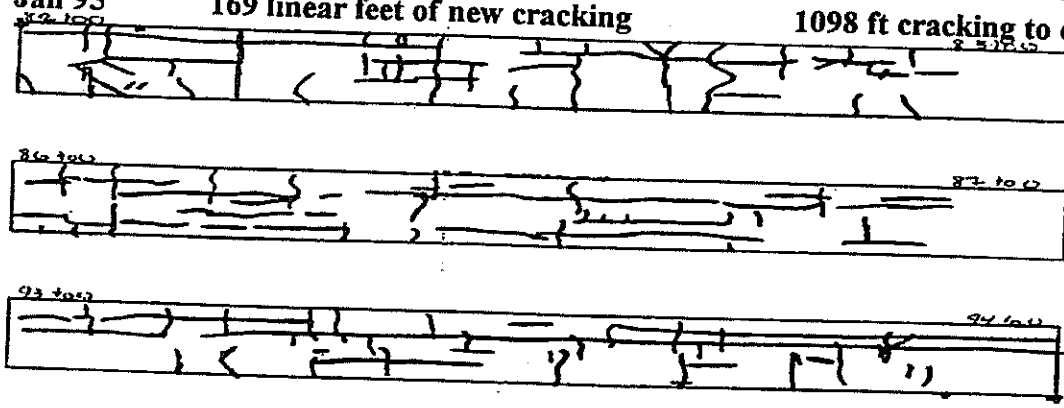


La 507 Crack Survey - Soil Cement (Page 2 0f 2)

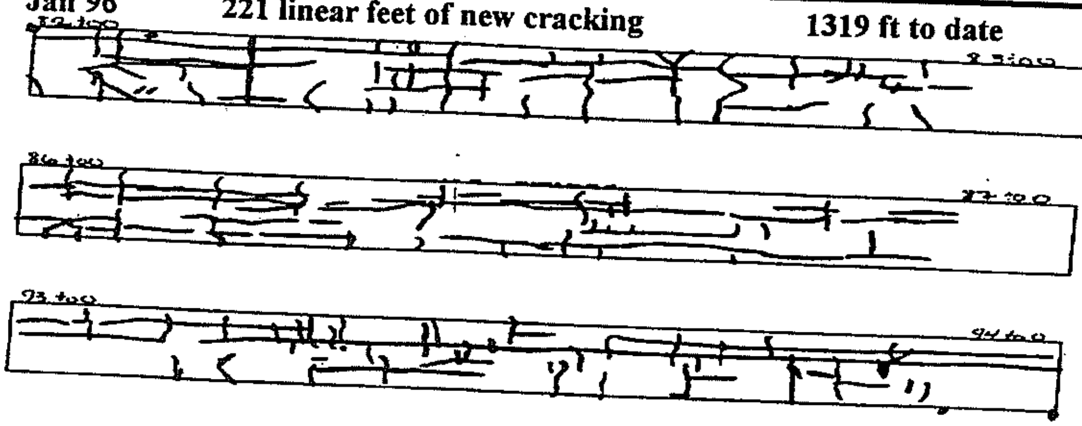
Dec 93 **107 linear feet new cracking** **929 ft cracking to date**



Jan 95 **169 linear feet of new cracking** **1098 ft cracking to date**

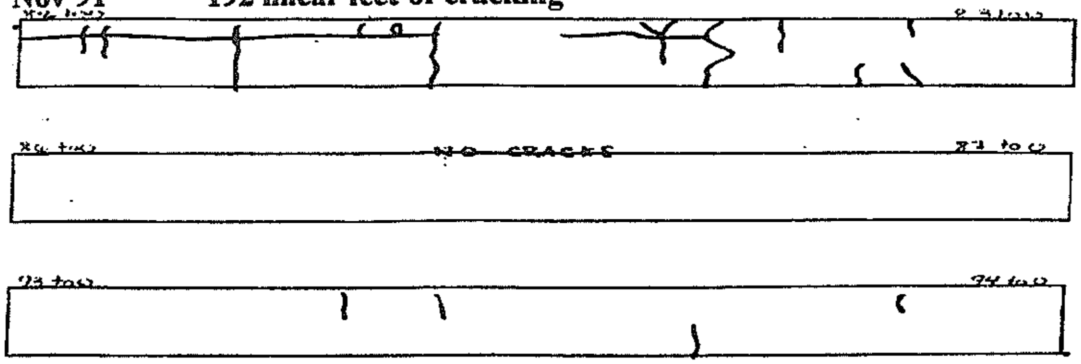


Jan 96 **221 linear feet of new cracking** **1319 ft to date**

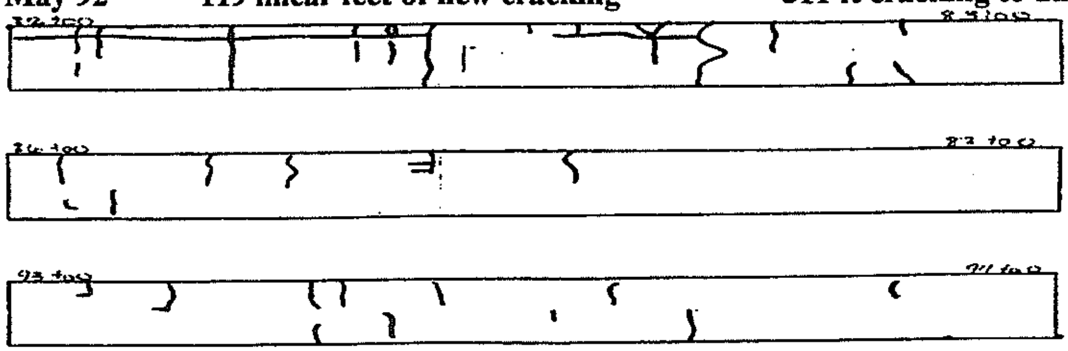


La 507 Crack Survey - Soil Cement (Page 1 0f 2)

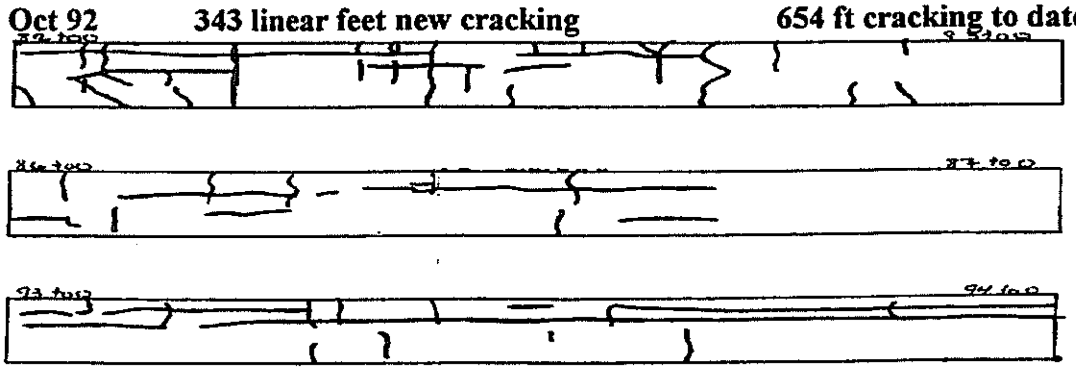
Nov 91 192 linear feet of cracking



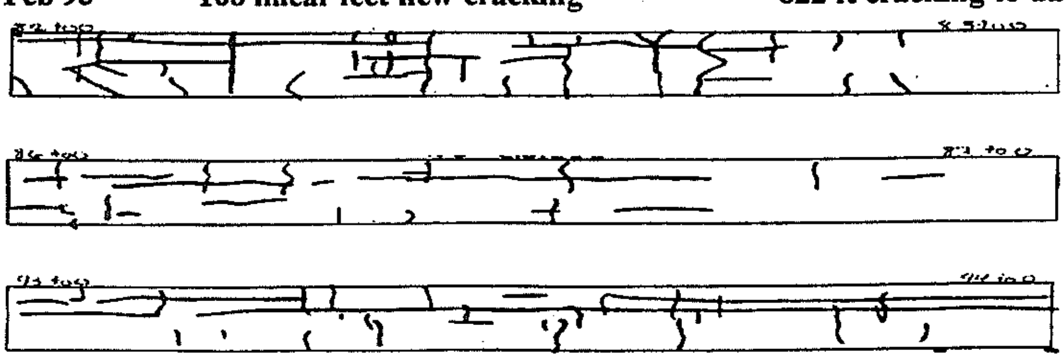
May 92 119 linear feet of new cracking 311 ft cracking to date



Oct 92 343 linear feet new cracking 654 ft cracking to date

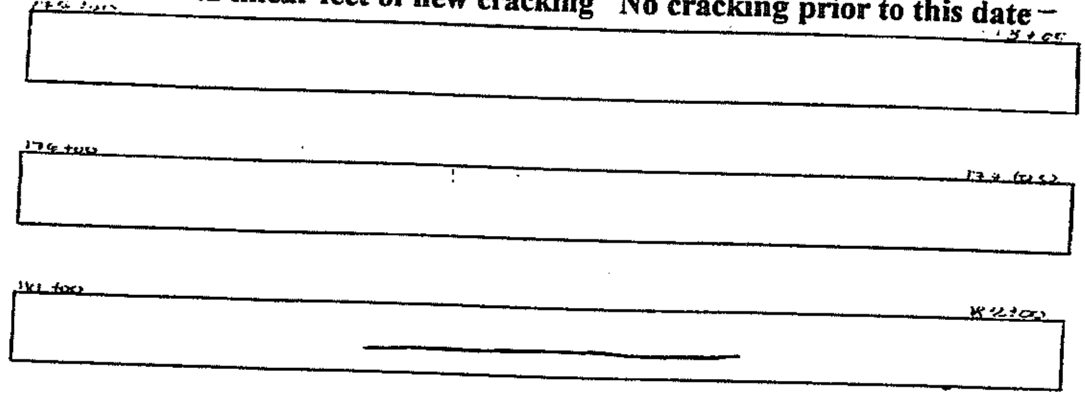


Feb 93 168 linear feet new cracking 822 ft cracking to date

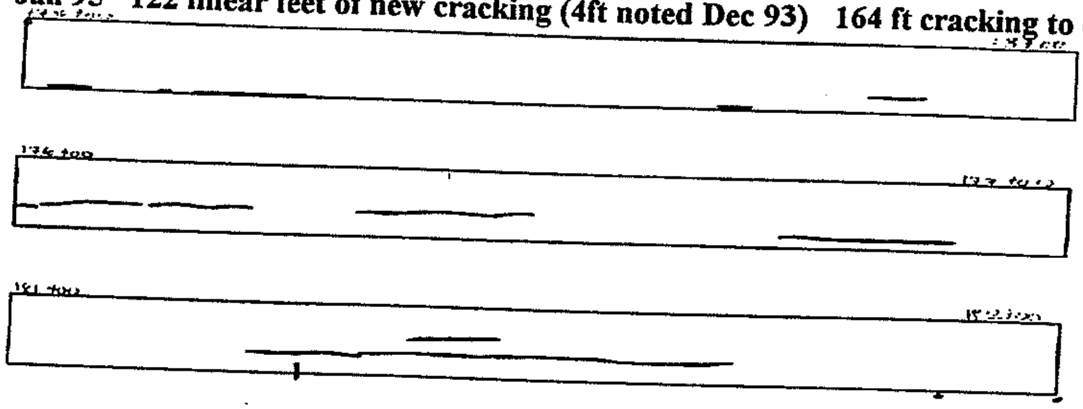


La 518 Crack Survey - 3% Lime + 6% Fly Ash

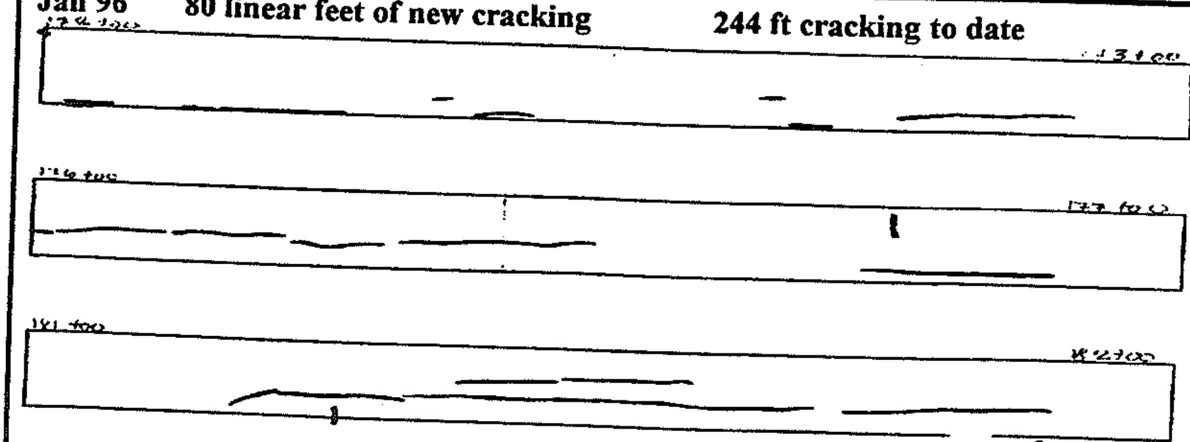
Feb 93 42 linear feet of new cracking No cracking prior to this date



Jan 95 122 linear feet of new cracking (4ft noted Dec 93) 164 ft cracking to date

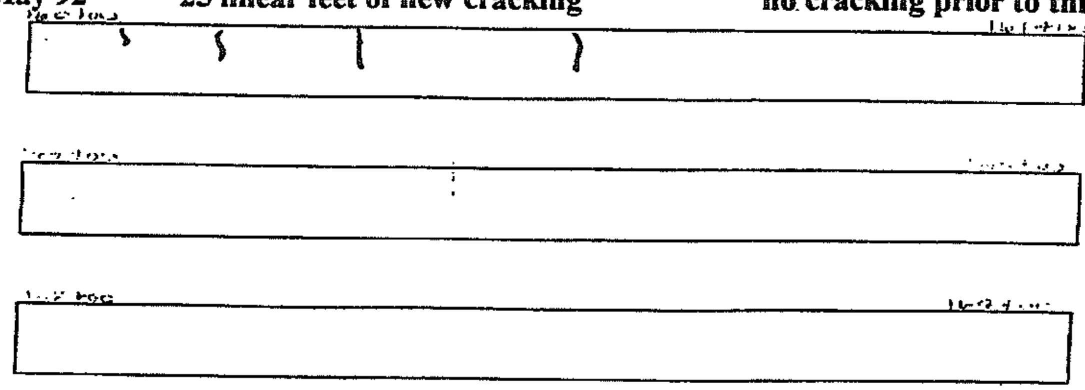


Jan 96 80 linear feet of new cracking 244 ft cracking to date

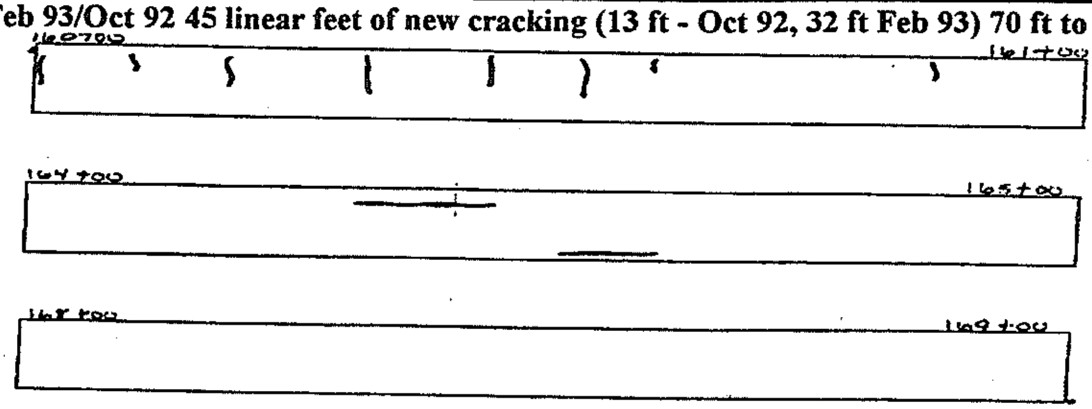


La 518 Crack Survey - 2% Lime + 4% Fly Ash

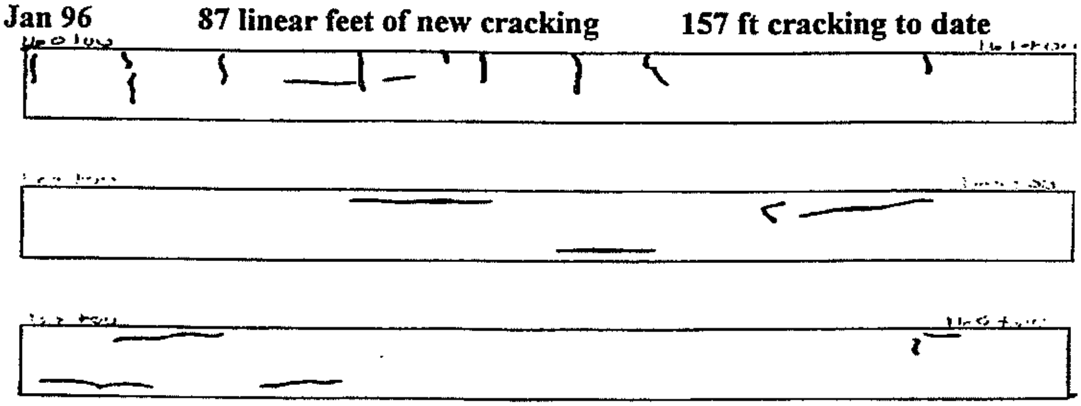
May 92 25 linear feet of new cracking no cracking prior to this date



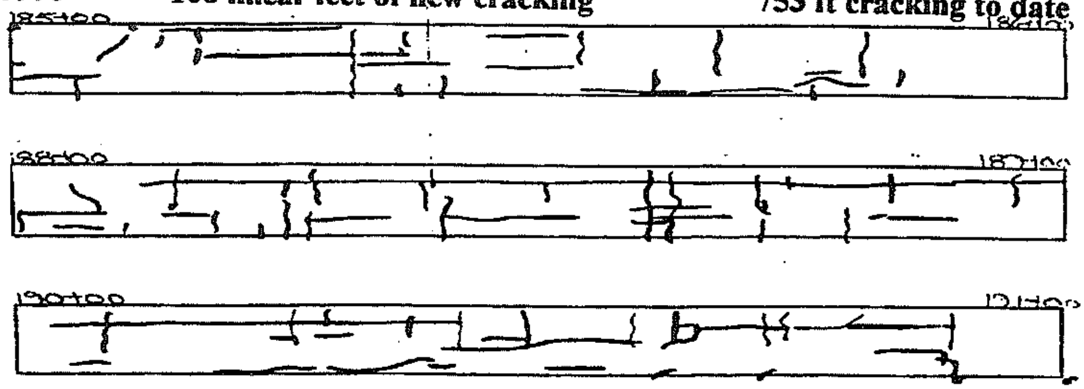
Feb 93/Oct 92 45 linear feet of new cracking (13 ft - Oct 92, 32 ft Feb 93) 70 ft to date



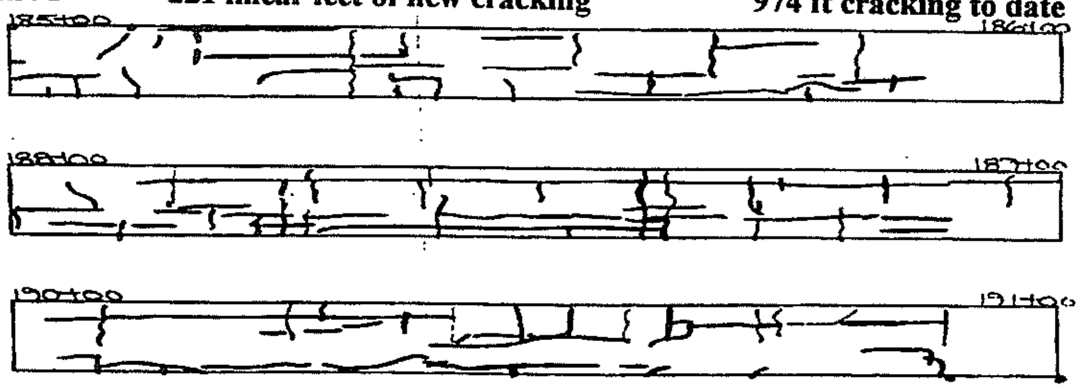
Jan 96 87 linear feet of new cracking 157 ft cracking to date



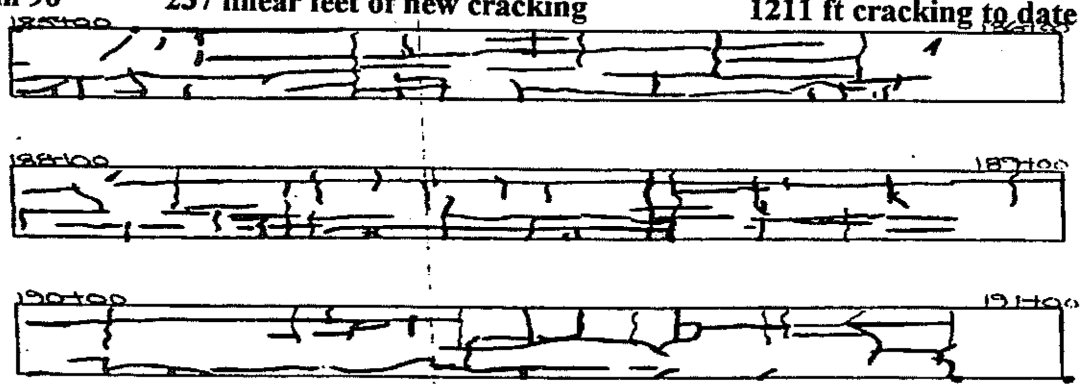
Dec 93 — **108 linear feet of new cracking** — **753 ft cracking to date**



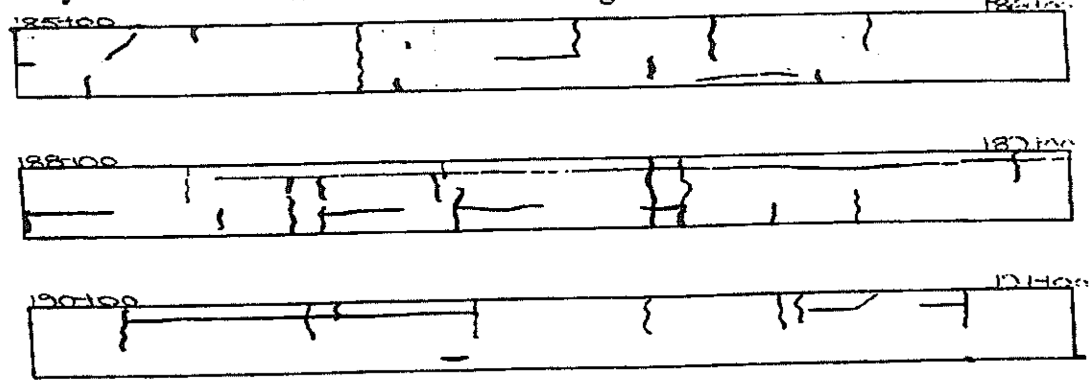
Jan 95 — **221 linear feet of new cracking** — **974 ft cracking to date**



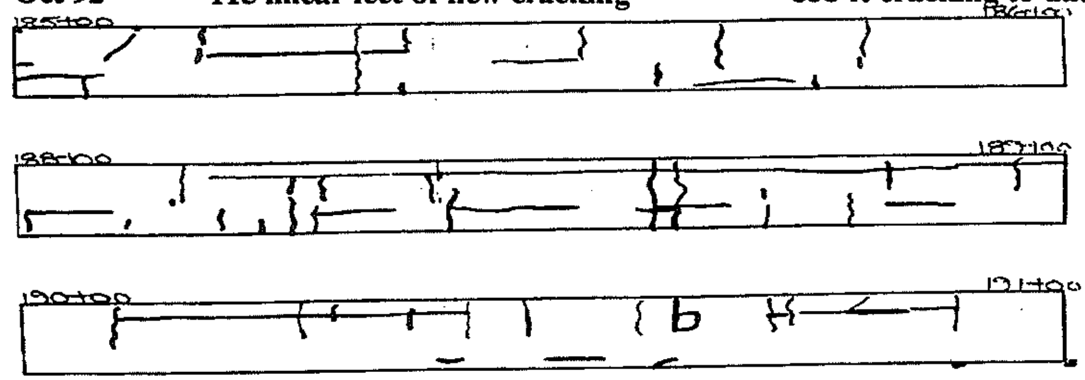
Jan 96 — **237 linear feet of new cracking** — **1211 ft cracking to date**



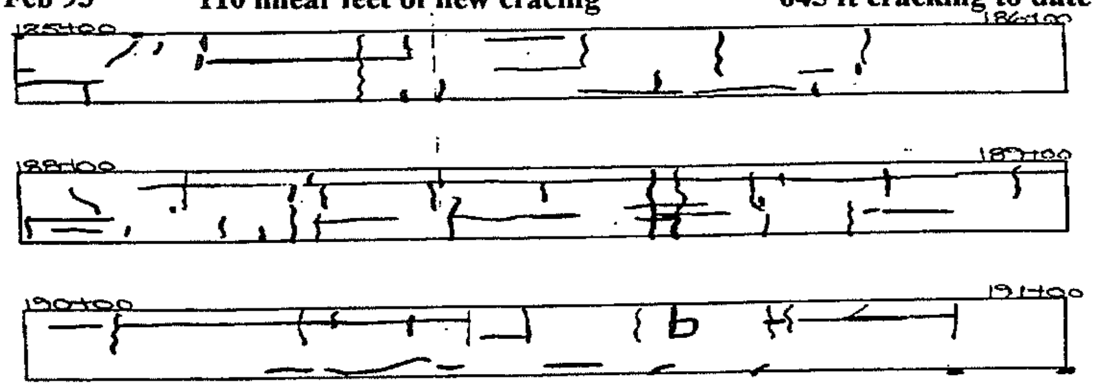
May 92 **87 linear feet of new cracking** **420 ft cracking to date**



Oct 92 **115 linear feet of new cracking** **535 ft cracking to date**



Feb 93 **110 linear feet of new cracing** **645 ft cracking to date**



Crack Survey Methodology

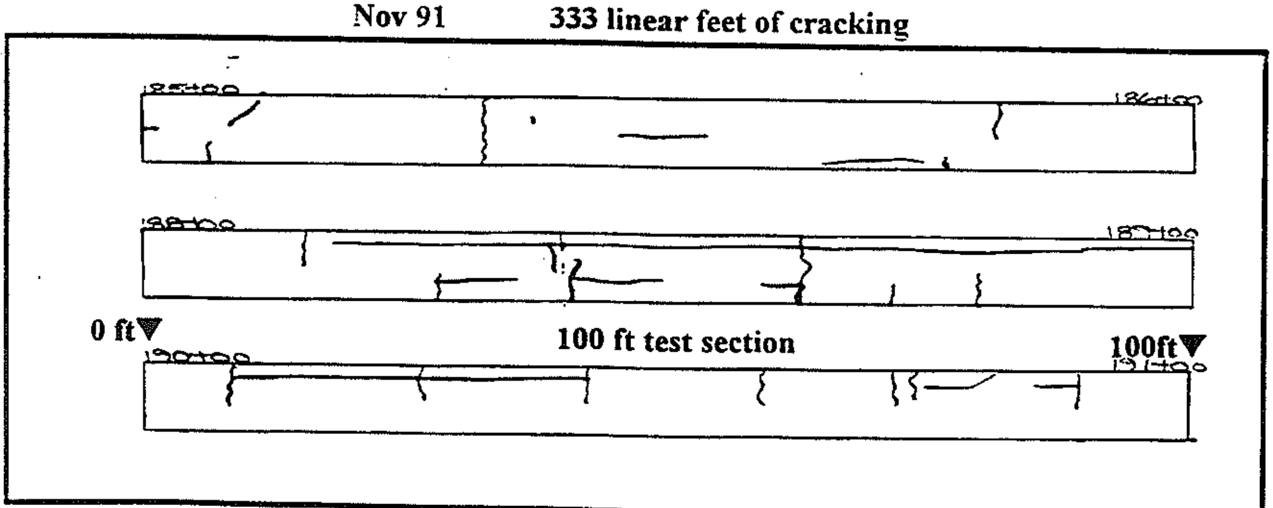
Crack surveys were taken concurrently with pavement evaluations using Dynaflect on the following dates: November 1991 (approximately six months after construction), May 1992, October 1992, February 1993, December 1993, January 1995, January 1996. A distance measuring wheel was used to obtain a rough estimate of the length of pavement cracks and corresponding sketches were made on test forms scaled to represent 100 foot long test sections. Sketches of cracks were color coded corresponding to the date of the survey. Notes were made on the survey sheets describing any cracks that were not hairline. An effort was made to achieve consistency by using the same person to perform the survey at each interval. Linear measurements were later determined from the field surveys by manual calculation.

After the completion of the January 1996 survey, the sketches were redrawn for inclusion in this report for a graphic comparison of crack propagation in the different treatment zones.

The reference grid and field notes have been removed from the reproductions of the survey sheets and the lines representing cracking have been darkened for greater clarity. Digitizing the crack maps and manipulating them for reproduction was accomplished by using Winfax and WordPerfect 6.1, and annual calculation of measurements was checked using Intergraph.

LA 518 Crack Survey - Soil Cement (continued next page)

Nov 91 **333 linear feet of cracking**



Appendix C

Dynaflect data - Structural numbers and subgrade modulus

Structural Numbers - - LA 518							
2% Lime + 4% Fly Ash							
Sta. No.	**5/91***	**8/91**	**5/92**	**2/93**	**12/93**	**1/95**	**1/96**
161+00	1.1	5.8	5.0	4.5	4.5	4.5	5.1
163+00	1.6	4.7	4.7	4.6	4.9	3.8	4.1
165+00	1.2	4.1	4.2	3.6	4.0	3.0	3.2
167+00	0.6	4.2	4.7	3.8	4.3	3.8	4.2
169+75	0.9	4.1	4.2	3.8	3.9	3.9	3.7
AVG	**1.1**	**4.6**	**4.6**	**4.1**	**4.3**	**3.8**	**4.1**
3% Lime + 6% Fly Ash							
172+00	1.4	4.1	3.4	2.3	3.0	2.2	1.7
174+50	0.8	4.5	4.5	3.5	4.5	3.7	2.7
175+00	1.0	4.6	4.4	3.7	3.9	3.2	3.7
179+00	1.3	5.6	4.7	4.6	4.8	3.9	4.3
180+00	1.3	4.0	3.6	3.8	3.5	3.6	3.5
182+00	1.4	3.9	4.0	3.6	4.0	3.0	3.4
AVG	**1.2**	**4.5**	**4.1**	**3.6**	**4.0**	**3.3**	**3.2**
Soil Cement							
200+00	1.6	3.7	-	-	-	-	-
197+00	1.1	4.7	2.3	4.0	4.4	3.8	3.9
195+00	1.8	4.6	3.8	4.0	3.9	3.5	3.5
192+00	1.2	4.3	2.8	3.4	4.2	3.9	4.0
190+00	1.8	4.6	4.2	3.9	4.2	3.2	3.8
185+00	2.2	5.5	5.3	5.0	4.9	4.8	5.1
AVG	**1.6**	**4.6**	**3.7**	**4.1**	**4.3**	**3.8**	**4.1**
*** 5/91 reading taken previous to overlay**							

NOTE: All base courses are overlaid with 3.5 inches of asphalt.

Subgrade Modulus (PSI) LA 518							
2% Lime + 4% Fly Ash							
Sta. No.	**5/91***	**8/91**	**5/92**	**2/93**	**12/93**	**1/95**	**1/96**
161+00	17,000	25,000	26,000	21,000	24,000	16,000	18,000
163+00	7,200	17,000	10,000	7,600	9,500	9,000	9,200
165+00	9,300	20,000	12,000	12,000	13,000	12,000	10,000
167+00	13,000	26,000	21,000	21,000	18,000	18,000	14,000
169+75	18,000	30,000	26,000	21,000	26,000	22,500	18,000
AVG	**12,900**	**23,600**	**19,000**	**16,520**	**18,100**	**15,500**	**13,840**
3% Lime + 6% Fly Ash							
172+00	22,000	34,000	29,000	18,000	27,000	21,000	23,000
174+50	9,800	18,000	18,000	13,000	15,000	10,000	14,000
175+00	9,200	20,000	17,000	9,700	14,000	11,000	9,800
179+00	11,000	21,000	24,000	12,000	22,000	12,000	16,000
180+00	8,500	23,000	16,000	8,400	13,000	9,700	9,800
182+00	18,000	27,000	25,000	14,000	22,500	16,000	18,000
AVG	**13,083**	**23,833**	**21,500**	**12,517**	**18,917**	**13,283**	**15,100**
Soil Cement							
200+00	11,000	27,000	26,000	-	-	-	-
197+00	14,000	29,000	27,500	22,500	24,000	17,000	22,500
195+00	7,600	27,000	26,000	21,000	22,000	12,500	14,500
192+00	11,000	28,000	26,000	21,000	23,000	14,000	18,000
190+00	9,000	22,000	25,000	11,000	18,000	14,500	12,000
185+00	12,500	23,000	23,000	14,000	21,000	15,000	14,000

AVG	**10,850**	**26,000**	**25,583**	**17,900**	**21,600**	**14,600**	**16,200**
* **5/91 reading taken previous to overlay**							

NOTE: All base courses are overlaid with 3.5 inches of asphalt.

LA 507 Structural Numbers						
2% Lime + 4% Fly Ash						
Sta. No.	8/91*	5/92	2/93	12/93	1/95	1/96
56+00**	1.1	3.6	3.4	2.2	1.4	0.4
57+00	1.9	4.9	4.2	5.6	4.1	3.7
58+00	1.5	4.5	4.0	4.4	3.2	3.1
59+00	2.2	4.5	3.9	4.7	3.5	3.5
60+00	1.6	4.8	4.1	4.3	3.7	3.5
61+00	1.6	4.8	4.2	4.6	3.3	3.4
62+00	1.5	4.8	4.3	4.4	3.5	3.1
63+00	1.9	5.5	5.4	4.9	4.2	4.3
64+++	2.3	5.4	5.0	4.6	4.0	4.0
65+00	2.2	5.5	5.2	4.7	3.8	4.8
66+00	1.2	5.4	5.5	5.7	3.5	4.2
AVG	1.7	4.9	4.5	4.6	3.7	3.8

* Pre Overlay

** Sta. 56+00 in severely cracked area. Not included in 1995 and 1996 average.

LA 507 Structural Numbers						
3% Lime + 6% Fly Ash						
Sta. No.	8/91*	5/92	2/93	12/93	1/95	1/96
68+00	1.8	5.7	5.5	5.8	4.8	4.6
69+00	1.7	5.6	5.3	5.6	4.4	4.1
70+00	3.3	6.1	5.5	6.0	4.9	5.2
71+00	3.1	5.7	4.8	3.8	4.0	4.0
72+00	2.8	6.1	5.4	5.9	4.6	4.8
73+00	3.7	5.8	5.3	5.4	4.2	4.4
74+00	2.6	5.3	4.5	4.0	3.6	3.6
75+00	2.0	4.9	4.9	5.1	4.0	3.8
76+00	1.9	5.2	5.4	5.4	4.3	4.4
77+00	2.2	5.1	5.3	4.9	3.7	3.9
78+00	2.2	5.4	5.0	5.5	4.0	4.4
AVG	2.5	5.5	5.2	5.2	4.2	4.3

* Pre-overlay

LA 507 Structural Numbers						
Soil Cement						
Sta. No.	8/91*	5/92	2/93	12/93	1/95	1/96
82+00	2.5	5.5	4.4	4.7	3.3	3.1
83+00	2.1	5.3	4.2	4.3	4.4	5.0
84+00	1.8	5.3	4.6	5.6	3.6	4.1
85+00	1.7	4.6	4.4	5.2	2.7	3.7
86+00	1.6	4.5	4.3	4.2	2.6	3.4
87+00	1.1	4.7	4.3	4.4	3.5	3.9
88+00	1.4	4.5	4.5	4.4	3.4	3.9
90+00	1.0	4.2	4.4	4.5	3.3	3.9
91+00	0.6	3.4	2.9	3.1	2.5	2.3
93+00	1.0	4.2	3.5	4.3	2.4	2.4
94+00	0.9	4.2	4.8	4.2	3.1	4.0
95+00	1.0	4.7	4.1	3.7	2.5	3.2
AVG	1.4	4.6	4.2	4.4	3.1	3.6

* Pre-overlay

LA 507 Subgrade Modulus(PSI)						
2% Lime + 4% Fly Ash						
Sta. No.	8/91*	5/92	2/93	12/93	1/95	1/96
56+00**	9,000	9,900	7,200	6,400	3,800	3,000
57+00	6,900	8,000	6,800	7,500	5,200	3,700
58+00	9,000	9,200	7,700	8,500	6,500	4,500
59+00	8,800	14,500	9,200	11,000	8,400	7,000
60+00	12,000	15,500	9,300	18,000	9,200	8,000
61+00	13,000	16,000	9,700	19,000	12,000	8,600
62+00	17,000	16,000	9,300	20,000	8,800	11,000
63+00	20,000	25,000	17,500	26,000	15,000	10,500
64+++	23,000	26,500	22,000	30,000	22,000	15,000
65+00	24,000	25,500	22,500	29,000	22,500	12,500
66+00	19,000	22,000	16,000	21,000	17,000	9,800
AVG	14,700	17,100	12,473	17,855	12,660	9,060

* Pre-overlay

** Sta. 56+00 in severely cracked area. Not included in 1995 and 1996 average

LA 507 Subgrade Modulus(PSI)						
3% Lime + 6% Fly Ash						
Sta. No.	8/91*	5/92	2/93	12/93	1/95	1/96
68+00	12,000	13,000	9,800	11,000	8,200	6,200
69+00	9,800	14,000	8,800	12,000	9,000	7,600
70+00	9,400	12,000	7,200	12,000	8,000	6,600
71+00	11,000	16,000	8,000	16,000	8,800	6,900
72+00	10,000	17,000	8,000	12,500	9,000	6,500
73+00	10,000	14,500	9,000	12,000	8,200	4,800
74+00	13,000	17,000	7,200	7,200	7,900	4,300
75+00	9,700	14,000	8,000	13,000	8,200	7,200
76+00	11,000	13,000	9,000	12,000	8,800	6,300
77+00	13,000	22,000	15,000	19,000	12,000	7,000
78+00	12,500	22,000	13,500	17,000	11,000	8,200
AVG	11,036	15,864	9,409	13,064	9,009	6,509

*Pre-overlay

LA 507 Subgrade Modulus(PSI)						
Soil Cement						
Sta. No.	8/91*	5/92	2/93	12/93	1/95	1/96
82+00	18,000	20,000	17,000	21,000	16,000	15,000
83+00	19,000	21,000	15,000	19,000	10,000	9,500
84+00	16,000	17,000	9,000	16,000	10,000	8,700
85+00	16,000	9,500	7,000	10,000	7,800	7,700
86+00	7,700	6,300	4,200	6,800	4,300	4,100
87+00	7,800	5,500	3,900	6,000	3,800	3,600
88+00	9,500	8,000	5,800	8,500	5,400	6,600
90+00	8,700	9,000	6,000	8,900	5,600	6,400
91+00	17,000	14,000	9,200	13,000	9,000	8,000
93+00	11,000	9,500	6,500	8,800	7,400	7,100
94+00	19,000	23,000	9,000	21,000	13,000	10,000
95+00	18,000	19,000	9,000	18,000	11,500	11,000
AVG	13,975	13,483	8,467	13,083	8,650	8,142

* Pre-overlay

Appendix D
Economic Analysis

Method of economic analysis

Soil maximum density	=	124 lb/ft^3
Cement unit weight	=	94 lb/ft^3
Lime unit weight	=	35 lb/ft^3
Class C fly ash unit wt	=	75 lb/ft^3

Cost per ton of cement, lime, and fly ash:

Cement: $80.00
Lime: $80.00
Fly Ash: $26.50

The placement cost for soil cement 8.5 inches thick is $2.20 per square yard, and for lime/fly ash 10 inches thick is $2.50 per square yard.
Note: The placement cost is based on the contract price and may vary in other applications.

The lime/fly ash treatment is expressed in percent by weight while the cement used is percent by volume.

To convert to volume:
Lime 2 percent by weight : $(0.02 \times 124\ lb/ft^3)/35\ lb/ft^3$ = 7 percent by volume
Fly Ash 4 percent by weight: $(0.04 \times 124\ lb/ft^3)/75\ lb/ft^3$ = 6.6 percent by volume

Analysis of cost per linear foot

The analysis is based on a 1 foot long 26 ft. Wide section to calculate the cost per linear ft. Of roadway.

Base course width = 26 ft
Cement: 1' length x 26' wide x 8.5"/12" depth = 18.4 ft^3/linear ft roadway
Lime/fly ash: 1' length x 26' wide x 10"/12" depth = 21.7 ft^3/linear ft roadway

Weight per linear foot of additive is:
Cement = 18.4 ft^3 x 94 lb/ft^3 x 0.08 = 138.4 lb/linear ft
Lime = 21.7 ft^3 x 35 lb/ft^3 x 0.07 = 53.1 lb/linear ft
Fly Ash = 21.7 ft^3 x 75 lb/ft^3 x 0.066 = 107.4 lb/linear ft.

Material cost per linear foot

Cement: (138.4/2000) x 80 =$5.53
Lime: (53.1/2000) x 80 = $2.12
Fly ash: (107.4/2000) x 26.50 = $1.42

Placement cost per linear foot

Cement = $2.20 x 2.9 = 6.38/linear ft on 8.5" thickness
Lime/Fly ash = $2.50 x 2.9 = 7.25/linear ft on 10" thickness

TOTAL COST

Cement: 6.38 + 5.53 = $11.91/linear foot
Lime/Fly ash: 7.25 + 3.54 = $10.79/linear foot

For 3 percent and 6 percent by weight of lime/fly ash the cost goes up by $1.82/linear foot; therefore, the total cost will change as following:

Cement: $11.91 per linear foot
Lime/fly ash: $12.61 per linear foot

This public document is published at a total cost of $956.27. One hundred ninety copies of this public document were published in this first printing at a cost of $569.27. The total cost of all printings of this document including reprints is $956.27. This document was published by Louisiana State University, Graphic Services, 3555 River Road, Baton Rouge, Louisiana 70802, to report and publish research findings of the Louisiana Transportation Research Center as required by R.S.48:105. This material was printed in accordance with standards for printing by state agencies established pursuant to R.S.43:31. Printing of this material was purchased in accordance with the provisions of Title 43 of the Louisiana Revised Statutes.