SOIL CEMENT LOW VOLUME
ROADS IN ARKANSAS

by

Sam I. Thornton

COLLEGE OF ENGINEERING
THE UNIVERSITY OF ARKANSAS
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16. Abstract

This report covers an investigation of low volume soil cement roads in Arkansas which, according to District Engineers, have experienced high maintenance costs due to distress. Distress of soil cement roads was minor in many cases. Observed conditions at many of the test sites indicated only longitudinal and transverse cracks which are characteristic of most soil cement stabilized material.

In a comparison of a distressed section and a section without distress, unconfined compressive strength of the cement treated base was found to be the best indicator of highway performance. Density of the cement treated base was not a good indicator because high densities were found in the sections with both good and poor performance.

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FINAL REPORT

HIGHWAY RESEARCH PROJECT 48

conducted for

The Arkansas State Highway Department

in cooperation with

The U.S. Department of Transportation

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Arkansas State Highway Department or the Federal Highway Administration.

ABSTRACT

This report covers an investigation of low volume soil cement roads in Arkansas which, according to District Engineers, have experienced high maintenance costs due to distress. Distress of soil cement roads was minor in many cases. Observed conditions at many of the test sites indicated only longitudinal and transverse cracks which are characteristic of most soil cement stabilized material.

In a comparison of a distressed section and a section without distress, unconfined compressive strength of the cement treated base was found to be the best indicator of highway performance. Density of the cement treated base was not a good indicator because high densities were found in the sections with both good and poor performance.

GAINS, FINDINGS, CONCLUSIONS

Distress of Arkansas low volume soil cement roads was minor in many cases. Observed conditions at many of the test sites indicated only longitudinal and transverse cracks which are characteristic of most soil cement stabilized material.

Unconfined compressive strength of the cement treated base is the best indicator of highway performance. Density of the cement treated base is not a good indicator because density was high on all three highways in the final testing program.

IMPLEMENTATION

Implementation of this research will depend on the findings of an AHTD review of the design and construction procedures for low volume soil cement roads.

ACKNOWLEDGEMENTS

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Special thanks are due to Robert F. Hayden for conducting much of the field and laboratory work.

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INTRODUCTION

Some soil cement low volume roads in Arkansas have performed well, others have not. According to a 1976 survey of District Engineers, soil cement failures are most common in south and east Arkansas.

The effect of early distress is increased maintenance costs and the creation of poor riding surfaces. Maintenance costs of low volume roads are important because Arkansas has 11,558 miles of secondary roads compared to 3,531 miles of primary roads.

BACKGROUND

Most of the technology for soil cement roads was developed before the 1970s and was reported by the Highway Research Board and Portland Cement Association. The following information on cement types, reaction with soil, and design criteria is drawn mainly from the reports of those two organizations and laboratory tests conducted by the author.

Cement Types

Portland cement is manufactured in three types:

ASTM Type I	General Purpose - This type is used in most roadbed stabilization. A sand mortar cube is required to develop 5500 psi in 28 days.
ASTM Type II	Lower Heat Sulfate Resistant - This type can be used in massive applications such as dams, piers, and abutments.
ASTM Type III	High Early Strength - This type should be used where high early strength is required, for example, where traffic must be placed on the stabilized soil within a week or two. A sand mortar cube is required to develop 7500 psi in 28 days.

ASTM Type IV, a type which minimizes heat, and Type V, a maximum sulfate resistance type, also are produced but seldom are used in roadbed stabilization.

Reaction with Soil

Cement is most effective in stabilizing granular soils. Mixed with water, cement forms a paste which hardens to tobermorite gel thereby cementing the soil particles together. The very strong gel cements the particles with which it is in contact regardless of their size. Because clay has many more particles than sand, more cement is required in clay than in sand. In addition, sand is stronger than clay.

The generalized reaction of cement with water is:

$$C_3S + 2H = C_2SH + \text{FREE LIME}$$

and

$$C_2S + 2H = CSH + \text{FREE LIME}$$

where

C is CaO

S is SiO_2

H is H_2O

The calcium silicate gel crystalizes slowly to form the tobermorite gel.

Because free lime is released, some of the same cation exchange and flocculation that occur in lime stabilization also take place during the reaction, but the formation of the gel is of overriding importance.

Strength is the most important property that cement contributes to soil. Unconfined compressive strength is the easiest and most common measure of strength. Unconfined compressive strength of cement stabilized soils ranges from 200 to 2000 psi. The usual range of seven day design strength for soil cement is 300 to 700 psi.

Cement content and the soil type affect the seven day unconfined compressive strength of cement treated soils (Figure 1). Strength increases with increasing cement content. Coarse grained soils may have strength greater than 1000 psi at a cement content of 10%. In fine grained soils the increase is much less dramatic. Unconfined compressive strength for fine grained soils at 10% cement is typically less than 500 psi.

The strength of soil-cement mixtures increases with time but the rate of gain decreases after a month (Figure 2).

After a year or more, the rate of increase in strength is very slow. An increase in strength with time occurs in both coarse grained and fine grained soils.

An increase in density of a soil cement mixture will increase the unconfined compressive strength of that mixture (Figure 3). An increase in density, as measured by dry unit weight, of 10% may result in a 30 to 100% increase in strength. The rate of strength gain from an increase in density is slightly higher in coarse grained soils than in fine grained soils.

Curing temperature also affects the strength of soil cement mixtures (Figure 4). As the curing temperature increases, unconfined compressive strength increases. The rate of increase due to curing temperature is approximately linear between 20° and $50^{\circ}C$ ($70^{\circ}F$ and

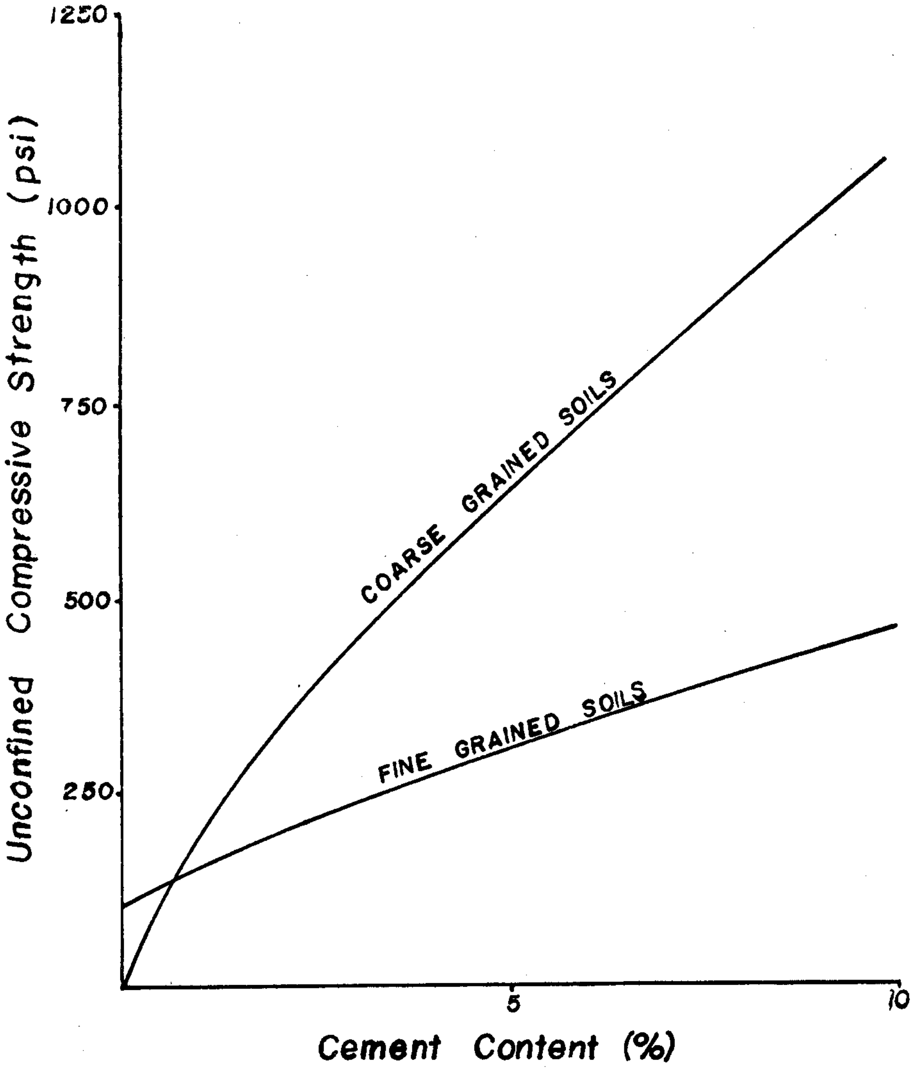


Figure 1. Effect of Cement Content on Strength

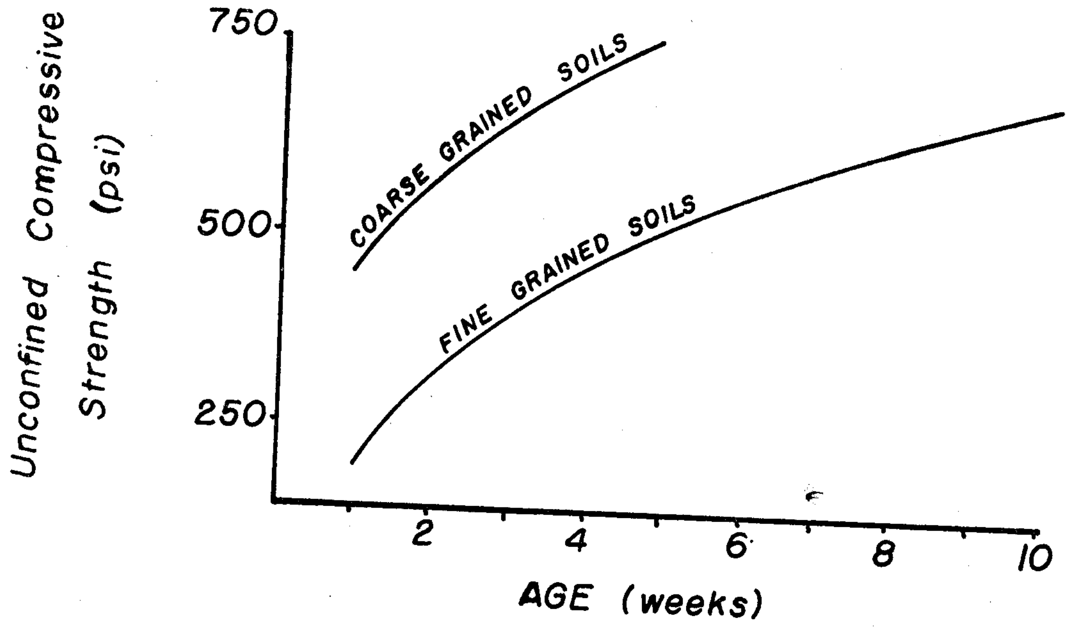


Figure 2. Effect of Curing Time on Strength

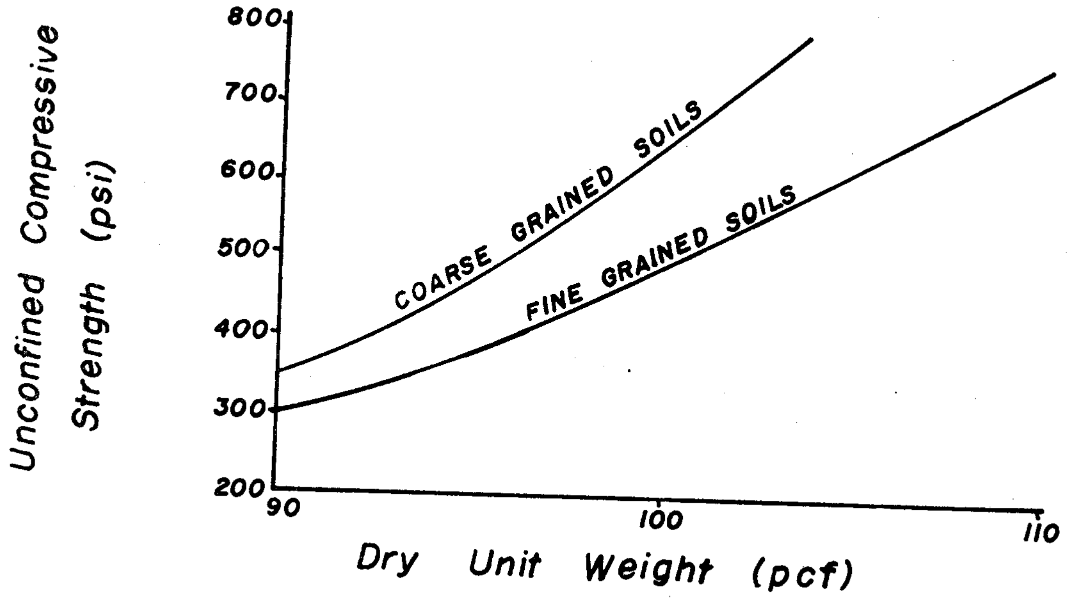


Figure 3. Effect of Density on Strength

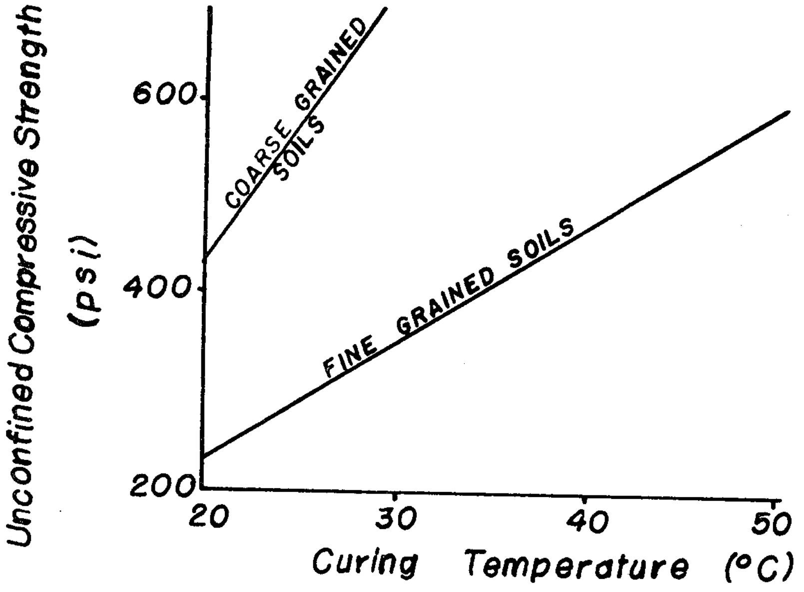


Figure 4. Effect of Curing Temperature on Strength

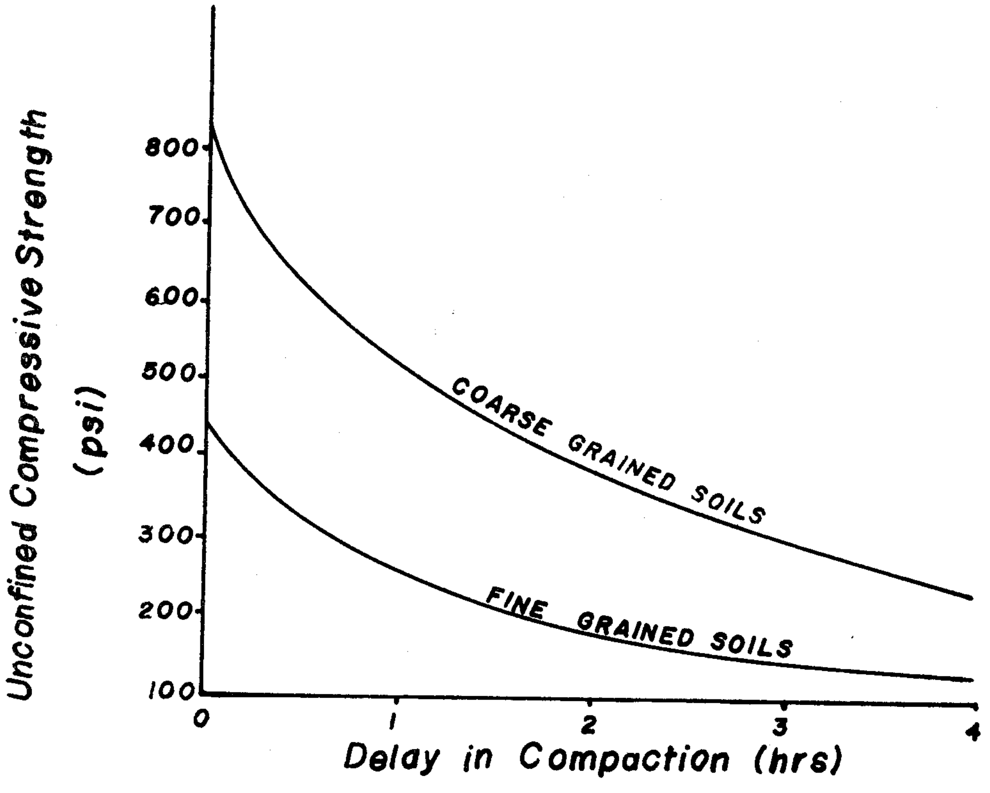


Figure 5. Effect of Delay in Compaction After Mixing on Strength

120°F). For this reason, soil cement bases for highways should be constructed in the summer while curing temperatures are high. The rate of strength gain from increased curing temperatures is more rapid in coarse grained soils than in fine grained soils.

A delay from the time of mixing to compaction significantly reduces the strength of soil cement (Figure 5). After cement is mixed with water, a reaction begins and continues with the passage of time. If soil, cement, and water are mixed but remain in a loose state, the mixture will gradually become cemented but the material will be weak.

Design Criteria

The design criteria for a roadway indicate the amount of cement to be used and the unconfined compressive strength required. As little cement should be used as possible to obtain the unconfined compressive strength desired. Cement above the amount required for strength is costly and may create a minor increase in shrinkage (Norling, 1973). An increase in longitudinal and transverse shrinkage cracks is not sure, however, and block cracking is reduced by increased strength (Zube et al., 1969, p. 60).

Unconfined compressive strength in the 300-1000 psi range usually is required in a 6 inch thick compacted roadbed base. The strength required depends on the amount and type of traffic and the strength and thickness of subbase and surface courses. Many roadways are designed on the basis of the recommendations of the AASHO test road. A good treatment of this method can be found in the text, Highway Engineering, 3rd edition, by Oglesby, 1975, pp. 481-486.

The strength requirement based on the design factors should be increased because field strengths are not as high as lab strengths. In an excellent report on cement treated bases in California, Zube et al. (1969) concluded, "It would appear advisable, therefore, to design new cement treated bases for a strength about 25 to 30 percent higher than considered necessary in the completed CTB."

An additional strength requirement commonly is included to compensate for a small percentage loss of weight, usually 10 to 14%, due to brushing in the freeze-thaw test. The freeze-thaw test, a durability test, is now out of favor because of the method of freezing the samples and the time required to conduct the test (Dempsey and Thompson, 1973). As a result, Dempsey and Thompson (1976) suggest a vacuum saturated unconfined compression test to replace the freeze-thaw test. Cumberage et al. (1976) conducted tensile strength tests on stabilized soil as a replacement for the standard freeze-thaw test. They concluded that a 68 psi tensile strength is necessary for freeze-thaw protection in Pennsylvania. Radd et al. (1977), in a study of fatigue behavior, concluded that tensile strength is a good indicator of fatigue resistance. Through questioning, they disclosed that the true tensile strength is 10% less than the split tensile strength which in turn is related to compressive strength.

The Portland Cement Association still recommends that durability testing, i.e., freeze-thaw and wet-dry tests, remain at the core of the design . . . "The three control factors for soil-cement construction -- density, moisture content and cement content -- are determined by standard ASTM laboratory tests that lead to a high degree of durability in the material rather than a specified compressive strength.

The tests were developed in such a way that the effect of any detrimental material in the soil - clay, organic materials, soft particles, etc. -- would cause a higher cement content for hardening due to the degree of chemical reaction of the cement with the soil (compressive strength is also a measure of this) and very importantly, how well the bonds of cementation hold together against repeated expansions and contractions caused by moisture absorption and loss, and volume changes due to temperature changes and freezing (compressive strength gives no indication of these effects). As a result, for many soils there is a poor correlation between the cement content required for a given compressive strength and the cement content required for durability" (PCA, Sept. 1978). Details of the PCA design procedure can be found in the following PCA publications:

Thickness Design for Soil Cement Pavements, 1970
Soil Cement Laboratory Handbook, 1971
PCA Soil Primer, 1973
Soil Cement Construction Handbook, 1969

Previous Study Findings

In an evaluation of "Service Performance of Cement-Treated Bases as Used in Composite Pavements," Zube et al. (1969) summarized the main causes of failure as:

1) insufficient cement content,
2) poor mixing,
3) over trimming of the compacted base,
4) insufficient base thickness,
5) inadequate compaction, and

6) poor quality or thin asphalt concrete.

A more recent study by Melacon and Shah (1973) shows mixing to be a major problem: "In-place mixing of cement with soil appears to be somewhat less than desirable. Results of 311 observations show a variation of ± 5% from the theoretical cement content."

Improvements in base performance can be made, however. Zube et al. (1969) found improvements from:

1) extending the base one foot into the shoulder,
2) plant mixing the base,
3) building the road in a temperate climate,
4) increasing the thickness of the asphalt concrete,
5) using a minimum base thickness of .5 feet,
6) making the thickness of any single layer a maximum of .5 feet,
7) using ASTM Type II cement, and
8) providing a minimum in-place base strength of 500 psi.

A 1963-1966 Arkansas study, HRC-9, was conducted to determine the performance of eight sections of newly constructed soil cement stabilized roadways (Hensley, October 1966). Although the study was terminated early, no extensive base failures were found. However, edge raveling was common and significant transverse and longitudinal cracking was reported through photographs. Also shown through photographs was the effective repair of cracks by resealing.

THE TESTING PROGRAM

Seventeen sections of soil cement stabilized state highways listed as distressed by District Engineers (Figure 6) were included in a preliminary testing program. The final testing program, formulated with the aid of a research subcommittee, included two of the distressed sections from the preliminary program and a different section for comparison which has no distress (Figure 7).

Interviews

As a part of the investigation, interviews with Highway Department officials, including design, testing, construction and maintenance officials, were conducted to obtain opinions about possible causes of the failures. The interviews included an inspection of the highways listed as distressed by the District Engineers.

The interviews were of little help in determining the cause of distress in the highways. In addition, little was learned from the inspection trips becuase the highways, with the exception of one or two, had recently been resurfaced in a special resurfacing program. It was apparent from the inspection trip, however, that no single problem such as poor drainage or unusual subsoil explained the distress.

Roadway Background

Investigation of the background of distressed highways included the following items:

a) type wheel loads,

b) use of road,

c) general terrain,

Figure 6

PRELIMINARY TEST SECTIONS

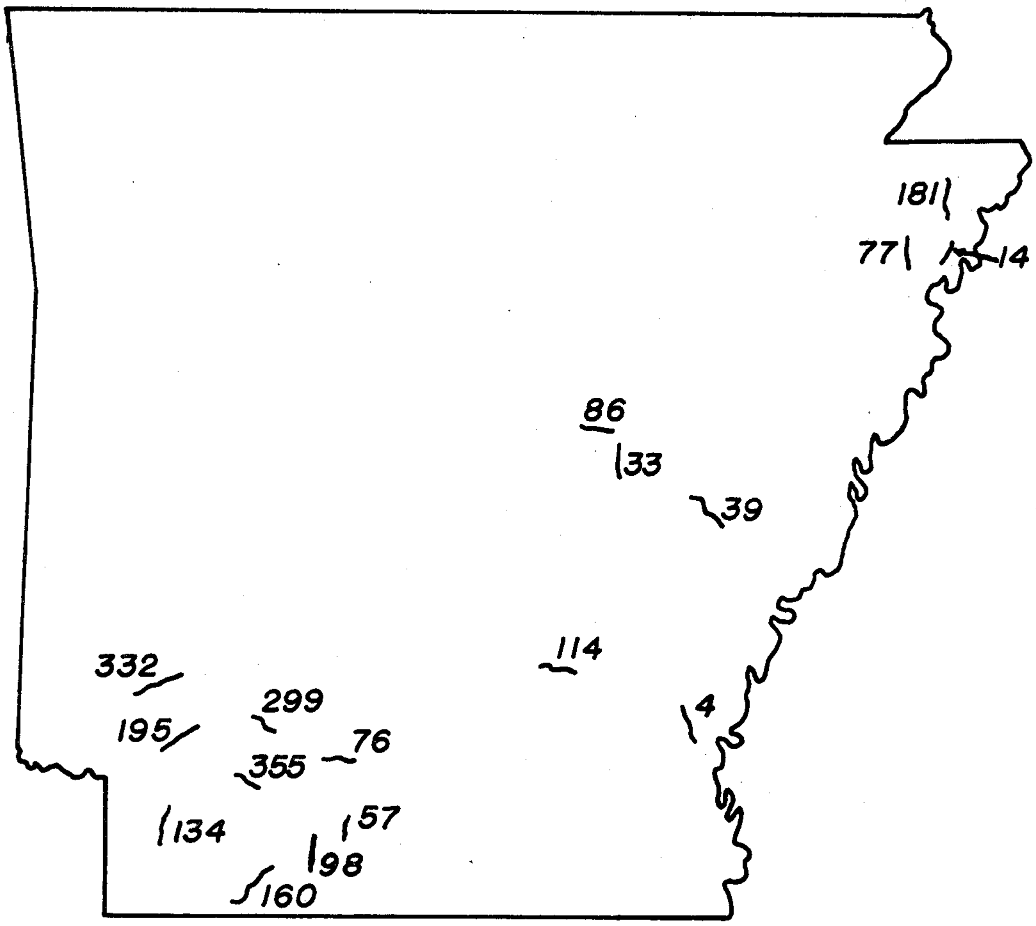
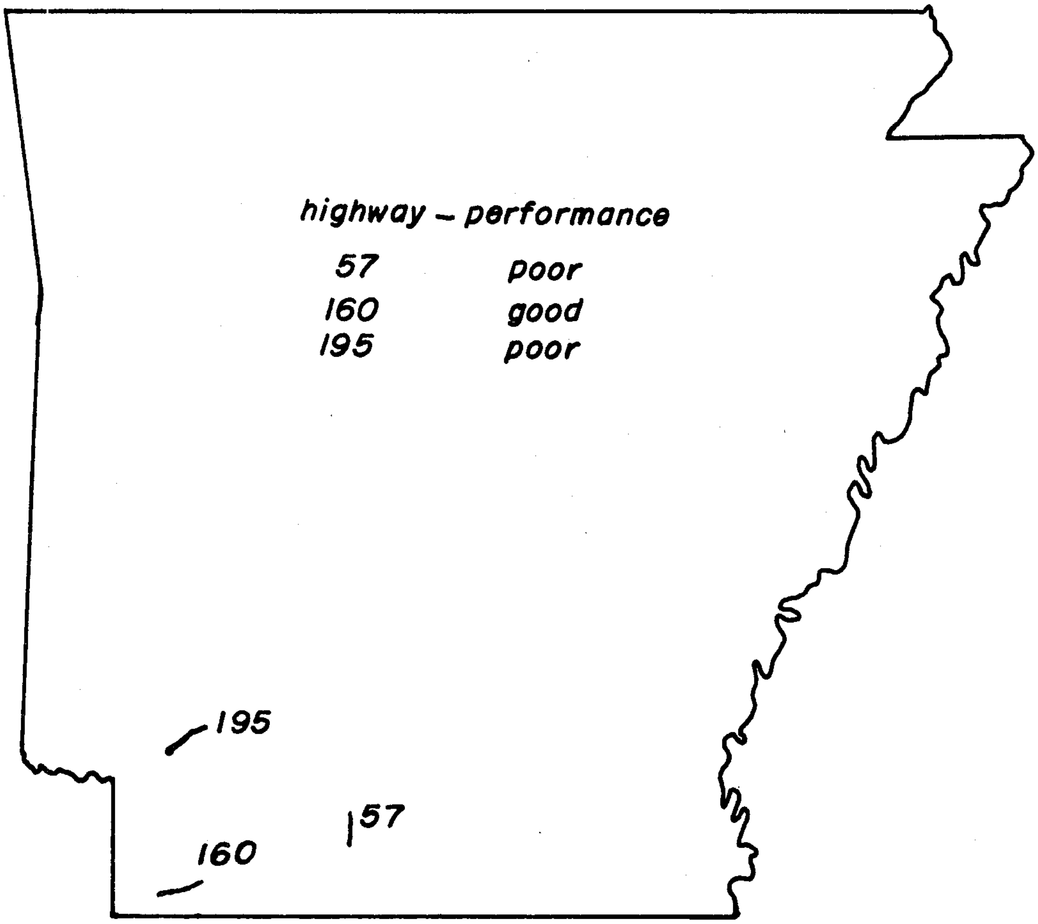


Figure 7

FINAL TEST SECTIONS



highway	performance
57	poor
160	good
195	poor

d) ADT (average daily traffic) at time of design,

e) Agriculture Department soil classification,

f) type of distress or overlay,

g) overload violations,

h) select material used,

i) typical section

j) construction practices used

k) present traffic counts

The wheel loads generally were light with an occasional very heavy load. For example, Highway 114 was subjected to local rural automobile traffic and an occasional timber or gravel truck. Exceptions to the light loading were noted for State Highways 39, 134, and 181 which were subjected to very heavy wheel loads.

All of the roads in the study were in rural or agricultural use except State Highway 4. Highway 4 was in agricultural use until 1974 when construction began on a paper mill and later a bean grainery.

Traffic volume did not explain the distress. Table 1 is a comparison of the traffic volume at the time of design with the volume at the beginning of the study (1976). Time of design is taken as the date completed less one year. Average daily traffic, ADT, was highest on Highway 160, but did not exceed 1100 vehicles per day.

Traffic volumes alone give little explanation of distress. A few heavy loads, not necessarily overloads, especially during wet or thawing conditions, will distress the pavement structure more than all the light traffic during the design life. In the case of the soil-cement roads in the study, however, there is no reason to believe that an unusual volume of heavy loads occurred during wet or thawing

TABLE 1

Traffic Volume for Preliminary Test Sections

State Highway	Design Year	Traffic Volume (ADT) In Design Year	Traffic Volume (ADT) In 1976
39	1970	220	410
114	1966	395	850
4	1962	125	340
195	1970	170	340
332	1970	130	390
134	1971	100	190
299	1971	110	200
355	1974	110	130
86	1971	320	340
33	1965	325	600
33	1958	100	440
76	1966	50	280
57	1971	500	750
160	1961-65	750	1100
98	1970	350	300
181	1967	140	600
77	1972	140	280
14	1967	300	250

conditions.

Most area subgrade soils, as classified by the Agriculture Department, are loam. Poor subgrade soils were expected because the highways are located in south and east Arkansas where many subgrade soils are poor.

Most of the highways showed no distress at the time of inspection because they were resurfaced in a major resurfacing project just before the beginning of the investigation.

A search of the records of overload violations did little to explain the distress. Overload violations were concentrated on a few highways, usually the main routes. Very few overload violations were recorded for the low volume roads included in the study, with the exception of Highway 196, which heavy trucks may use to avoid weighing scales.

Without exception all the roads were constructed by cement stabilizing the top 6 inches of a select material fill. Total base thickness ranged from 6 to 12 inches. A typical cross-section with a schedule of base thicknesses as determined by Highway Department records is given in Figure 8.

Typed copies of the data sheets for background are in Appendix A. The information on the sheets is summarized in Table 2.

Preliminary Testing Program

Preliminary testing included the taking of cores of the cement treated base and disturbed samples of subgrade material. Two sites per roadway were selected for cores. Originally, cores were to be taken at distressed and nondistressed sections of the highways, but

TYPICAL CROSS SECTION

State Highway	Total Base Thickness (in)
33	6
39	8
57	8-11
86	8
98	9
114	7
134	8
160	8-10
195	8
299	7
332	7
355	7

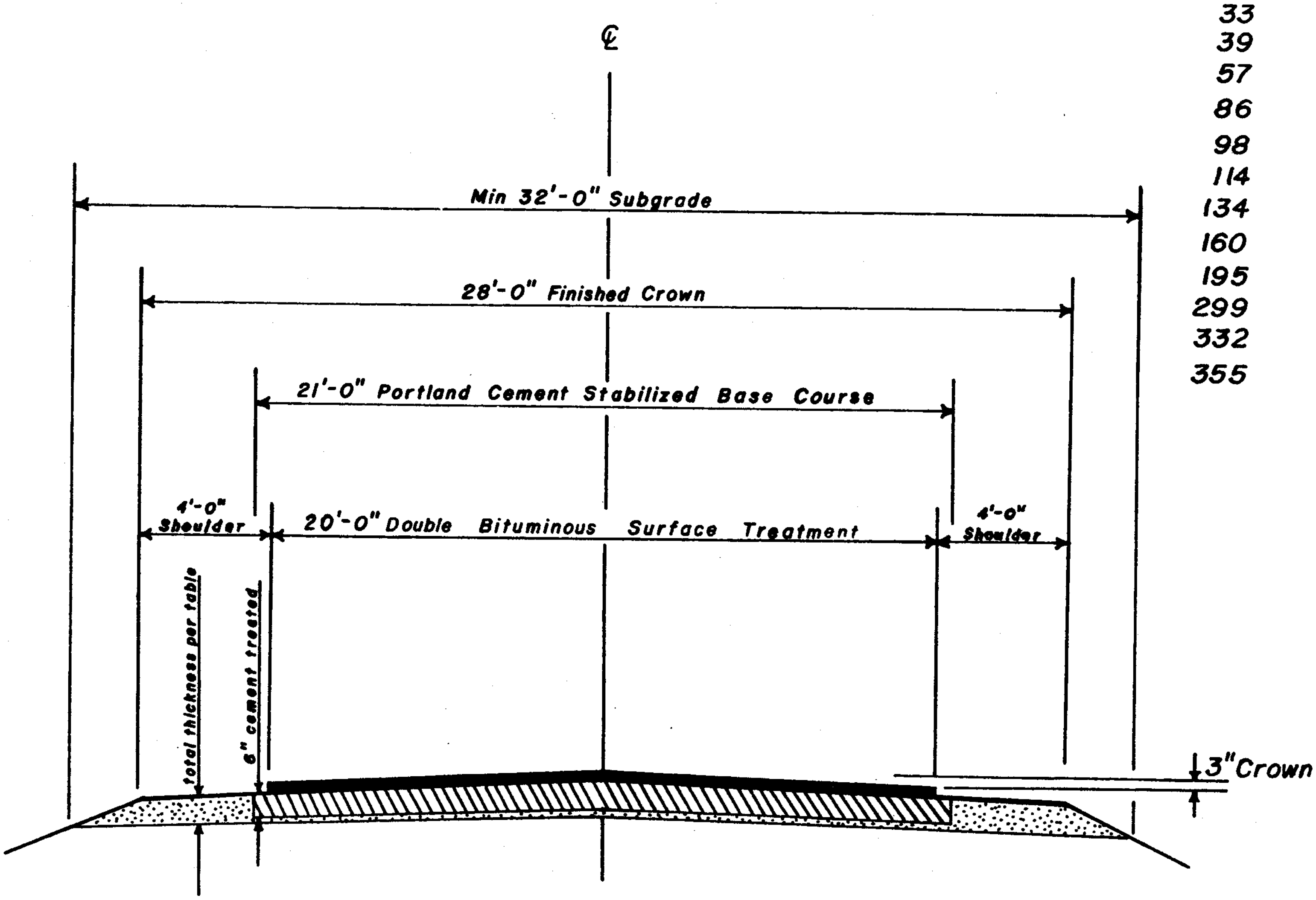


Figure 8

Table 2

Summary of Roadway Backgrounds

Hwy.	Road Use	Design Cement	AASHTO Class	General Drainage	Wheel Loading	Constr. Proced.	Observed Conditions	Repair Method	Comments
39	Rural	10.5%	A-3(0)	Poor	Grain trucks	MIP*/SM-6	Longituninal cracks	Seal	Blow-up failure
114	Farm	6%		Good	Timber/ gravel	Gravel added	Base failure	Overlay cut base 12-36"	½" premix over poured cracks
4	Farm			Poor	Grain/ gravel	SM-2 12"	Longitunidal crack base	Cut base- 7-8% premix sealed	Constr. Pot-latch Plant
195	Rural Farm	8%	A-2-4(0)	Poor	Gen. light w/ overloads		Base		Bypass for weigh scales
332	Rural Farm	7.5%	A-2-4(0)	Moderate-good	Gen. light w/ overloads	SM-4	Longitudinal & transverse cracks		Clay subgrade
299	Rural Farm	6.5%	A-2-4(0)	Good	Light		Slight cracking		Some timber hauling
355	Rural	5%	A-4(0)	Good	Light w/ timber	MIP	No Failure		Observe low cement
14	Rural	6%		Poor	Farm	MIP	Slight Cracking	SBST	Sandy loam little distress

* MIP - mixed in place

TABLE 2 (cont.)

Hwy.	Road Use	Design Cement	AASHTO Class	General Drainage	Wheel Loading	Constr. Procedure	Observed Conditions	Repair Method	Comments
86	Rural Farm	10%	A-2-4(0)	Poor	Rice farming	MIP*/ SM-2	Ravel	?	Good contractor, smooth ride
33 Sect. 5	Rural	8%		Good	Grain/ timber	SM	Base Failures	SB-2/hot mix	
33 Sect. 6	Rural			Poor	Grain/ timber	SM	Base shrinkage	SB-2/hot mix	Roots in SM
76	Rec.			Good			New seal	Premix seal	
57	Rural	8.5%	A-2-4(0)			SM-2		Pour cracks	ACHMSC surface course
160	Rural	9%				SM		Premix and seal	
98	Rural	6%				SM-2 DBST		Premix and seal	
181	Farm	9%	A-2-4(0)	Poor	Grain	MIP/ SM	Base Failures	Asphalt/ sand	New surface
77	Rural Farm	9.5% 10.5%	A-3(0) A-2-4(0)	Poor	Farm	MIP/ SM	L&T cracks & ravel	2-300' patch	Poor subgrade
134		9.0%	A-2-4(0)	Poor	Farm	SM	Chunks	Rebuild	Corpos of Engineers hauled rip-rap

* MIP - mixed in place

because of the recent overlays the cores were taken at random in the sections. Cores were tested for density, strength, and moisture content. Disturbed subgrade samples were tested for moisture content, in-place density, R-value, liquid and plastic limits, and Proctor density.

Results from the preliminary testing program are given in Tables 3, 4, and 5. Table 3 includes the design data, e.g., percent cement and classification of the stabilized select material. The results from core strength and density tests are given in Table 4. Subgrade data are listed in Table 5.

Cement content ranged from 5 to 10.5% (Table 3). The select material which was stabilized was classified as A-2 or A-3 by the AASHTO system except that of Highway 355, which was classified A-4. Design density ranged from 109 to 133 pcf and optimum moisture content was low, 8 to 15%, as is expected in coarse grained soils.

Thickness of the cement treated bases was near the design thickness of 6 inches (Table 4). Only for Highway 332 were both cores less than 6 inches long. Compressive strength was low, however, in at least one of two cores from 13 of the 16 highways. Seventeen highways were included in the study but one, Highway 355, had no distress and was included for observation only. An analysis of the probable causes of low strength (Table 6) indicated the most common causes to be cement lenses, clay nodules, and organic matter (Figures 9, 10). In general, higher field density and lower field moisture content indicated higher compressive strength. For example, the 1300 psi of Highway 299 corresponds to a density of 114 pcf and moisture content of 9.4%, whereas the 210 psi of Highway 355 corresponds to 107 pcf and 13.5%.

TABLE 3

Summary of Roadway Design Data

Highway	Design Cement Content (%)	Base (SM) Material AASHTO Class	Design	
			Density (pcf)	Optimum Moisture (%)
39	10.5	A-3(0)	110 110	13.0 13.0
114	6		133 133	8.2 8.2
4	9-10		County Job	
195	8	A-2-4(0)	118 118	10.4 10.4
332	7.5	A-2-4(0)	116 116	13.8 13.8
299	6.5	A-2-4(0)	123 123	8.8 8.8
355	5	A-4(0)	122 122	11.5 11.5
86	10	A-2-4(0)	110 110	12.8 12.8
33	8		N.A.	N.A.
76			N.A.	N.A.
57	8.5	A-2-4(0)	111 111	12.3 12.3
160	9-10		111 111	11.6 11.6
98	7		120 120	10.3 10.3
181	9	A-2-4(0)	110 110	13.1 13.1

TABLE 3 (cont.)

Highway	Design Cement Content (%)	Base (SM) Material AASHTO Class	Design Density (pcf)	Design Optimum Moisture (%)
77	9.5	A-3(0)	109	14.9
	10.5	A-2-4(0)	109	14.9
14	6		N.A.	N.A.
134	9	A-2-4(0)	116	12.2
			116	12.2