FIELD EVALUATION PROGRAM OF CEMENT-TREATED BASES

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The purpose of this study is to improve or develop design criteria for cement-treated bases by means of field experiments using recommendations for implementation from laboratory studies on criteria for strength and shrinkage control of cement-treated bases and crack control in cement-treated bases. This paper presents information on the background of the research study, laboratory work, and field construction of experimental sections. It also includes a limited analysis of the laboratory and field test results. Tentative conclusions indicate that the present design criteria are valid and need no modification. Consideration should be given to using lime additive when high clay content (16 percent or more) is found in the base material. Sugar is a good retarding agent but also creates large cracks. If the cracks can be formulated and retained as fine hairline cracks, they will not be reflective on the pavement surface. Use of expansive cement and lime additive (two mixings) creates such fine hairline cracks. The undisturbed curing and the artificial traffic sections have recorded numerous fine cracks on the soil-cement but only a small amount on the pavement surface. From the standpoint of construction economy, providing the 7-day undisturbed curing practice is very expensive and inconvenient. Therefore, it is recommended that the undisturbed curing requirement be deleted and that construction traffic and necessary local traffic be allowed on the soil-cement during the 7-day period. These conclusions are preliminary pending a longer performance record of field experimental sections.

•TWO research studies using extensive laboratory testing and dimensional and model analyses were conducted by K. P. George (1,2) on the construction and testing of cement-treated base materials. Following are recommendations for implementation from his research work and discussion of these recommendations by the Research and Development Division of the Mississippi State Highway Department (MSHD).

Recommendations pertaining to the selection of soil and design of soil-cement mixtures are as follows:

1. Because shrinkage stresses are a function of the maximum shrinkage, which in turn is solely controlled by the -2μm clay particles, an effort should be made to use soils with as small a quantity of clay as possible and still remain consistent with the clay requirement for proper cohesion and strength. If the clay mineral in the soil is kaolinite, the clay content should not exceed 15 percent; however, the clay content should be limited to about 8 percent if the clay mineral is montmorillonite. If the soil contains both kaolinite and montmorillonite in some proportion, the ceiling should accordingly be interpolated between these limits.
2. Inasmuch as montmorillonite soil shrinks much more than kaolinite, its shrinkage potential warrants extensive investigation.
3. The use of large aggregates [at least 1 in. (25.4 mm) in diameter] in a soil-cement matrix often exhibits excessive shrinkage and therefore should be discouraged.

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4. The cement requirement stipulates that amounts of cement equal to or greater than that specified by freeze-thaw test criteria (ASTM D 560) be used.
5. Type II cement is recommended over Type I cement.
6. For minimal shrinkage cracking, it is highly desirable to replace 1 to 2 percent of cement with an equal amount of lime.
7. Expansive cement admixture is very effective in well-graded coarse grain soils.
8. Cracking can be minimized when a mixture of sugar and lime is added to the soil-cement mixture.

George also recommended the following to ensure sound construction and curing procedures.

1. As high frictional subgrade may serve to more evenly redistribute stresses caused by shrinkage and thereby reduce the incidence of cracking, it is proposed that soil-cement base be placed over rough subgrade. Accordingly, mix-in-place soil-cement construction is desired.
2. Soil-cement base should be compacted to the highest density possible. A minimum of 95 to 100 percent AASHTO T-180 is recommended. Soils with AASHTO T-99 density below approximately 115 lb/ft^3 (1842 kg/m^3) should be used with extreme precaution. Also, it is extremely important that soil-cement be compacted at the dry side of optimum moisture.
3. Most important of all, cracking can be minimized by adequately extended curing. The evaporation rate of water from the surface of a fresh soil-cement base is the most important factor influencing shrinkage and shrinkage cracking, and that rate is influenced by the temperature, relative humidity, and wind velocity of the air and temperature of the soil-cement. Accordingly, specifications should be changed to discourage casting of a soil-cement base at low humidity and in windy and hot weather.
4. By increasing the stiffness of the base shrinkage, cracking can be controlled. Because the stiffness is proportional to the third power of the thickness, the advantage in increasing the thickness is obvious.
5. When the design calls for a thickness of about 7 in. (178 mm) or more, it is desirable to compact the base in two layers that are properly bonded at the interface.

Based on George's recommendations MSHD conducted an informal study to determine the predominate clay mineral to be used for soil-cement construction. To date, 60 samples have been X-rayed, and all were found to be predominately kaolinite with trace illite or montmorillonite. The clay content of these 60 samples ranged from 8 to 16 percent. These met all the requirements George outlined in his recommendations. Inasmuch as the 60 samples come from different districts of Mississippi and represent a general condition of the base material throughout, it does not seem that the highway department will have any problem in the selection of soils.

At the request of the department, George conducted a special study on three samples to evaluate and compare the department's procedure of determining cement content with those developed by the ASTM and PCA. The present department design criteria are based on 7- and 14-day unconfined compressive strengths. The results (Table 1) indicate that the department's criteria are about 1 percent higher than those specified by the freeze-thaw (ASTM D 560) test. This also meets George's recommendation.

The present specification requires a specified density of 97 to 101 percent AASHTO T-134 for the compaction control of soil-cement bases. Department engineers involved in the study felt that the 95 to 100 percent AASHTO T-180 compaction effort George recommended is not feasible under the present field construction practice. It may also cause damage to the subgrade soil.

Most soil-cement construction in Mississippi is done by mix-in-place operation. During mixing operations, the pulverizing machine actually roughens the subgrade to a certain degree, and this could be considered as a frictional surface. The two-layer, soil-cement construction used in the past years was quite unsatisfactory (Fig. 1). The department no longer uses the two-layer construction design. In another study at the Virginia Highway Research Council (3), it was found that sugar-lime admixture can be used successfully for retarding the hardening of cement-treated soils in highway construction.

Table 1. Comparison of cement content determination using MSHD, ASTM, and PCA procedures.

Soil Number and County	Predominant Clay Mineral	AASHTO Classification	Cement Percentage on Volume Basis: Recommended by Highway Department	PCA Shortcut Procedure	ASTM Freeze-Thaw Requirement
1-A, Attala	Kaolinite with trace illite and montmorillonite	A-2	8	9	7
2-A, Attala	Kaolinite with trace montmorillonite	A-2	6½	8	6½
3-A, Carroll and Montgomery	Kaolinite with trace montmorillonite	A-2	7½	8	6½

Figure 1. Two-layer soil cement failure.

Table 2. Physical properties of soils used.

Item	Number
Percent passing	
No. 10	100.00
No. 40	87.00
No. 60	50.00
No. 200	21.00
No. 270	20.00
Silt, percent	6.00
Clay, percent	14.00
Colloids, percent	13.00
Dust ratio	24.06
Plasticity index, percent	N.P.
Raw soil standard dry density, pcf	115.6
Raw soil optimum moisture content, percent	12.8
Cement required to stabilize, percent	6.5

Table 3. Standard density and optimum moisture contents of control and experimental sections.

Section	Standard Density (pcf)	Optimum Moisture (percent)
Control	113.5	13.6
Experimental		
Lime (two mixings)	112.5	15.4
Lime (one mixing)	115.0	14.0
Sugar	115.7	13.9
Type II cement (same as control)	114.3	14.3
Type K cement	111.3	14.3
7-day undisturbed curing	115.7	13.5
Artificial traffic	115.7	13.5
Less cement	112.2	14.3
Less cement and increased thickness	115.8	13.1

Note: 1 pcf = 16.018 46 kg/m^3.

RESEARCH PROJECT DESIGN

The site selected for this research study is located in Winston County on Miss-395. Cement contents used in all the experimental sections are expressed in percentage by volume of raw soil, and lime and sugar contents are expressed in percentage by weight of raw soil.

From station 140+00 to 150+00 there will be a control section. Thickness of this section will be 6 in. (152 mm), and cement content will be 6.5 percent.

The experimental sections are as follows:

1. Station 150+00 to 160+00 (with lime additive)—thickness = 6 in. (152 mm), cement content = 4.5 percent, and lime content = 10.5 lb/yd^2 (5.7 kg/m^2) or 2 percent. Lime will be placed and mixed first and allowed to mellow 6 days, then cement will be added, and the total base remixed.
2. Station 160+00 to 170+00 (with lime additive)—thickness = 6 in. (152 mm), cement content = 4.5 percent, and lime content = 10.5 lb/yd^2 (5.7 kg/m^2) or 2 percent. Lime and cement will be applied and mixed in one mixing operation.
3. Station 170+00 to 180+00 (with sugar additive)—thickness = 6 in. (152 mm), cement content = 6.5 percent, and sugar content = $\frac{1}{3}$ lb/yd^2 (0.18 kg/m^2) or $\frac{1}{16}$ percent.
4. Station 180+00 to 190+00 (with Type II cement)—thickness = 6 in. (152 mm), and Type II cement content = 6.5 percent.
5. Station 190+00 to 200+00 (with Type K expansive cement)—thickness = 6 in. (152 mm), and expansive cement content = 6.5 percent.
6. Station 200+00 to 210+00—thickness = 6 in. (152 mm), and cement content = 6.5 percent. This section requires undisturbed curing. During the first 7 days after completion of the cement-treated base on this section (including the curing membrane), all traffic and equipment will be kept off the cement-treated base and routed around another road.
7. Station 210+00 to 219+00—thickness = 6 in. (152 mm), and cement content = 6.5 percent. This section requires artificial traffic during the curing period in addition to any traffic that must be maintained under the contract. After the required density has been obtained on this section and the curing membrane has been placed, the surface will immediately be sanded as lightly and as uniformly as necessary to prevent "picking up" the curing membrane. Thereafter at least three complete coverages by the pneumatic tire roller, or by something comparable used in obtaining the required density, will be made once in the morning and in the afternoon of each of the next successive 7 days in the curing period. In addition, a dual wheel dump truck loaded to the maximum load will traverse each lane of the section 10 times during each day. Such loads will cover the entire width of the cement-treated course, exclusive of the outside 1 ft (0.3 m). If, at any time during such maximum loadings, there is evidence that permanent damage to the base is beginning to occur, such maximum dual wheel loading will be stopped.
8. Station 219+00 to 228+00—thickness = 6 in. (152 mm), and cement content = 4.5 percent. This experimental section uses less cement.
9. Station 228+00 to 236+58—thickness = 8 in. (203 mm), and cement content = 4.5 percent. This section uses less cement and has increased base thickness.

LABORATORY TESTING AND RESULTS

Soil used for the cement-treated base is a uniform A-2(0) sand clay material that has about 14 percent clay content. The X-ray diffraction pattern indicated that the clay mineral was in the form of kaolinite.

The average daily traffic for this project is less than 1,000, and according to the department's roadway design procedure, the thickness of the soil-cement base is 6 in. (152 mm). Physical properties of soils are given in Table 2. The cement content (6.5 percent by volume) for the control section was determined by the present department design criteria, which are based on the 7- and 14-day unconfined compressive strength. The moisture-density relationships for the control and experimental sections are given in Table 3.

Effect of Delay Mixing on Soil-Cement Strength

Test specimens were made at different delayed mixing times, ranging from 1 to 48 hours, so that the effect of delay mixing on the strength of soil-cement could be studied. These samples were cured for 7 days and then tested for unconfined compressive strength. Figure 2 shows the results of these tests.

Sugar was tried at a different percentage and with and without lime. The sugar and lime percentage shown in Figure 3 is calculated from the weight of the raw soil. The mixture with 4½ percent cement, 2 percent lime, and ⅜ percent sugar almost completely killed the cementing action and provided extremely low strength. The mixture with 4½ percent cement, 2 percent lime, and 1/16 percent sugar provided a strength of about 150 psi (1.04 MPa). This mixture provided 150 psi (1.04 MPa) throughout the delayed period from 1 to 7 hours. The curve also shows that, when delayed 24 to 48 hours, the mixture had a gain of strength of about 40 psi (0.28 MPa). The mixture with 4½ percent cement and 2 percent lime (one mixing) gives a curve that provides a strength of 250 psi (1.72 MPa) throughout the delayed period from 1 to 7 hours. The control mixture design with 6½ percent cement only showed a high strength of 500 psi (3.45 MPa) at normal mixing; however, the strength dropped sharply to about 200 psi (1.38 MPa) when delayed 3 hours. This indicates that it is very important in soil-cement construction for the contractor to compact the soil-cement mixture as soon as possible so that the designed strength can be achieved.

The experimental mixture with 6½ percent cement and 1/16 percent sugar provided the same 7-day strength as the control section when it was tested at normal mixing and, yet, at the end of the 7-hour delay, it still had a strength of 250 psi (1.72 MPa).

7- and 14-Day Strengths of Experimental Mixtures

Table 4 gives the 7- and 14-day strengths of all experimental mixtures. The department's current design procedure requires a strength of 500 psi (3.45 MPa) or above; however, on this experimental project, the various experimental designs also varied in strength, which ranged from 300 psi (2.07 MPa) to 500 psi (3.45 MPa).

CONSTRUCTION OF FIELD EXPERIMENTAL SECTIONS

Construction for the experimental soil-cement base section began on July 23, 1972, and was completed on August 2, 1972. A Bros Roto Mixer was used for the mixing operation. A sheepsfoot roller and ruber-tired roller were used for the compaction of the soil-cement. The 1-in. (25.4 mm) hot plant mix pavement was completed in September 1972. No special problem was encountered during the field construction.

Experimental section 5 using Type II cement was constructed with the same type of cement used in section 1, the control section, because the cement that the contractor used met the AASHTO specification for Type I and II cement.

FIELD MEASUREMENTS AND RESULTS

Time Lapse Between Mixing and Compaction

The present specification requires that water supply and pressure distributing equipment will be provided, which will permit the application, within 1 hour, of all water required to bring the section being processed to the required moisture content. Each increment of water added during mixing will be incorporated into the mix for the full depth to avoid concentration of water near the surface, and no portion of the mixture will remain undisturbed for more than 30 min before compaction. Initial compaction will begin immediately, and machining and compacting will continue in such manner that, and until, the entire depth and designated width of the cement-treated material is compacted to the required density within 2 hours from the time of beginning the mixing.

An effort was made during the field construction to study the effect of time lapse between mixing and compaction on the strength of soil-cement.

Figure 2. Effect of delay mixing on strength of soil-cement.

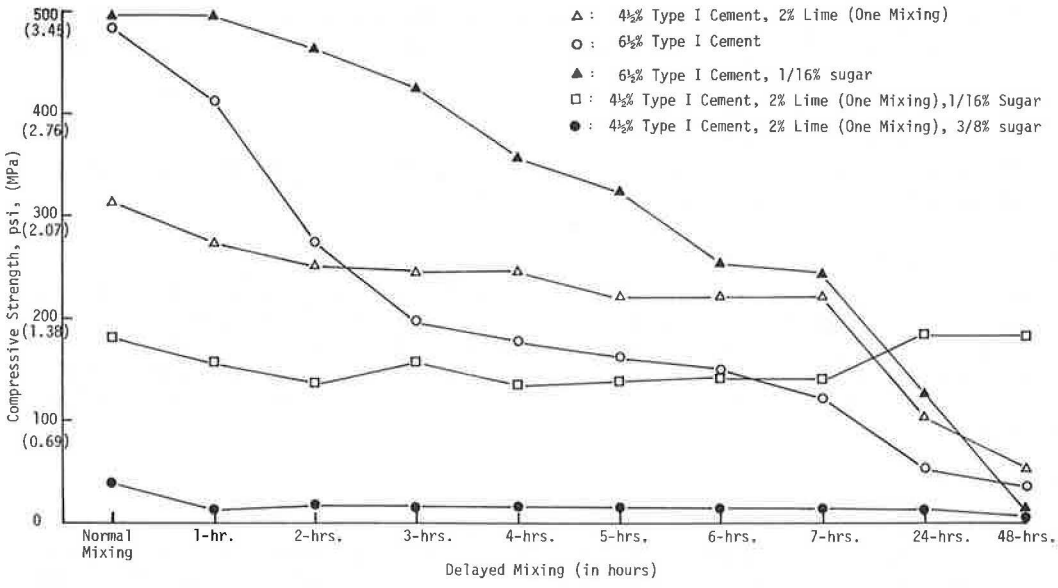
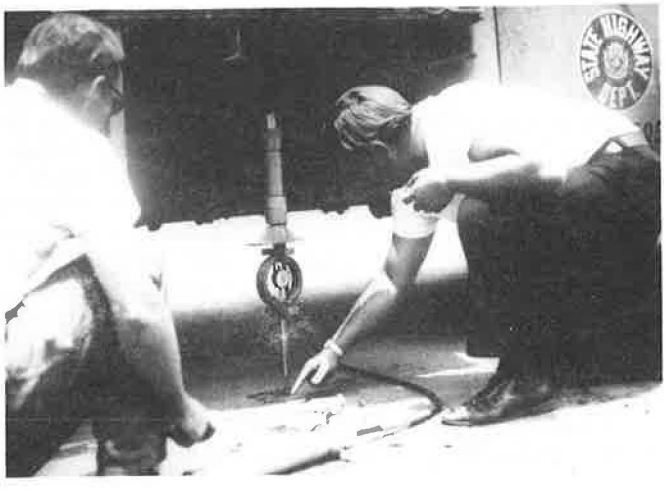


Table 4. All experimental mixtures at 7- and 14-day compressive strengths.

Experimental Mixtures	7-Day Strength (psi)	14-Day Strength (psi)
6½ percent Type I cement	485	577
4½ percent Type I cement, 2 percent lime (two mixings)	426	
4½ percent Type I cement, 2 percent lime (one mixing)	314	374
4½ percent Type I cement, 2 percent lime (one mixing), ⅜ percent sugar	40	32
6½ percent Type K expansive cement	370	
4½ percent Type I cement	346	
4½ percent Type I cement, 2¼ percent lime (one mixing), 1/16 percent sugar	183	263
6½ percent Type I cement, 1/16 percent sugar	497	549

Note: 1 psi = 0.006 894 757 MPa.

Figure 3. Penetration resistance test apparatus.



Field Moisture and Density

Field moisture and density measurements were obtained by nuclear and conventional methods (sand cone density and speedy moisture content were used as conventional methods).

Penetration Resistance Test

A homemade penetrometer apparatus was used during field construction to measure the penetration resistance. The apparatus is shown in Figure 3.

Cement Contents

So that the uniformity of the spreading and mixing operation could be studied, samples for cement contents determination were obtained during the compaction operation between stations 140 and 150. Cement contents were determined by X-ray.

In January 1973, cores were obtained between stations 140 and 150. The unconfined compressive strength and cement content of these cores were determined in the laboratory.

Deflection

Limited information on the deflection of the soil-cement was obtained during the field survey using the Dynaflect unit. The Dynaflect unit measures pavement deflection induced by an applied load. It is an electromechanical system consisting of a dynamic force generator, a motion measuring system that is mounted in a towed trailer, and five motion sensing geophones suspended from the towing arm of the trailer. The Dynaflect-measured deflections have good correlation with the Benkleman beam deflection measurements. Benkleman beam deflection is equal to about 20 times the Dynaflect deflections (unit in mils or mm).

Dynaflect deflection readings were conducted on the experimental section 7 days after its completion. At least four readings were obtained from each section.

Cracking

All visible cracks on the control and experimental sections were mapped when the soil-cement was 7 days old (in July 1972). The pavement surfaces were first mapped during September 1972, but no cracks were found. In June 1973, another field survey was made and cracks were mapped. Considerable cracking was recorded during this survey. Figures 4 through 13 show cracking maps of a 100-ft (30.5 m) section of the soil-cement and superimposed pavement selected from the control and experimental sections.

PRELIMINARY ANALYSIS OF RESULTS

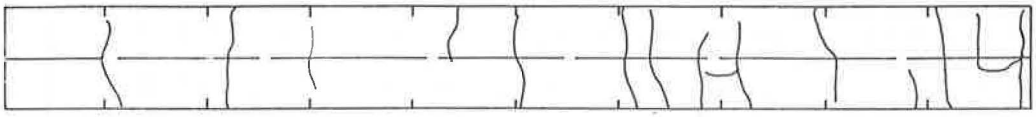
A summary of results is given in Table 5. All the sections have about the same elapsed time (except the sugar section), penetration resistance, and deflection. The field moisture content and density are all slightly lower than the specified values. The only data that show a considerable difference among the 10 sections are the crackings. The cracking index is calculated from all the cracks located on each control or experimental section by using the total footage of cracks divided by the total area. The unit for the cracking index is therefore in ft/ft^2 (m/m^2).

The present design criteria for soil-cement mixtures based on the 7-day compressive strength of 500 psi (3.45 MPa) for DBST or concrete pavement and 600 psi (4.14 MPa) for hot plant mix pavement appear to be on the high side. However, considering the uniformity of spreading operation and time lapse during the mixing and compacting, this high strength requirement provides a safety factor for the field mass production. Therefore, it is recommended that these criteria not be changed at the present time.

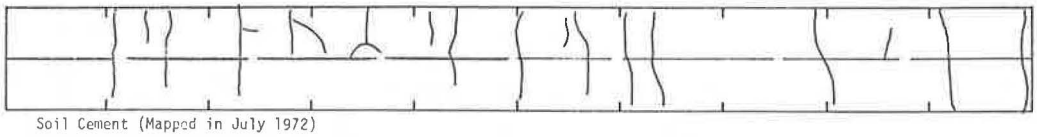
Sugar is a good additive to retard the setting time of soil-cement mixtures and thus provides the contractor more time to mix and compact the material. However, sugar also causes larger cracks on the soil-cement, which is most undesirable.

Lime should be a very useful additive when higher clay contents are found in the base

Figure 4. Cracking pattern of soil-cement base and superimposed pavement for control section.

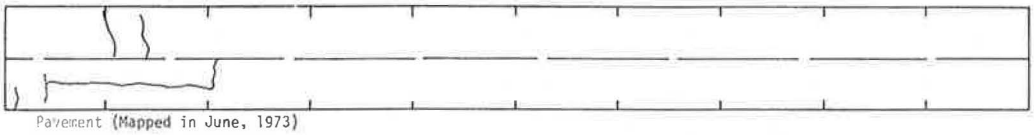


Pavement (Mapped in June 1973)

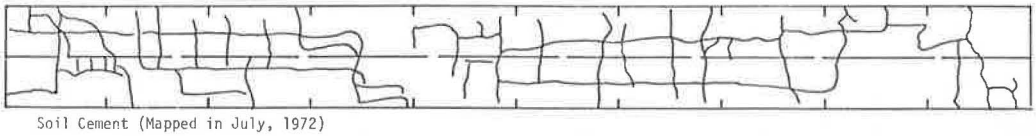


Soil Cement (Mapped in July 1972)

Figure 5. Cracking pattern of soil-cement base and superimposed pavement for experimental section with lime additive (two mixings).

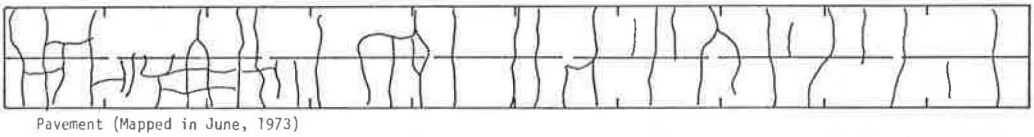


Pavement (Mapped in June, 1973)

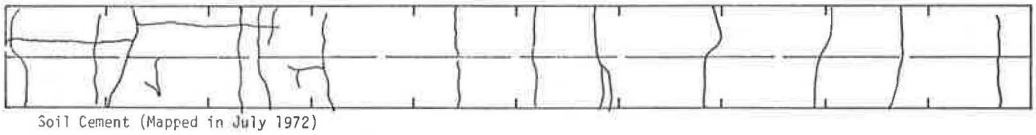


Soil Cement (Mapped in July, 1972)

Figure 6. Cracking pattern of soil-cement base and superimposed pavement for experimental section with lime additive (one mixing).

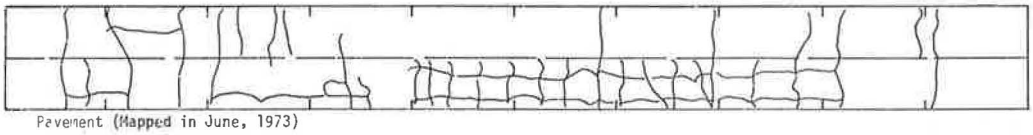


Pavement (Mapped in June, 1973)

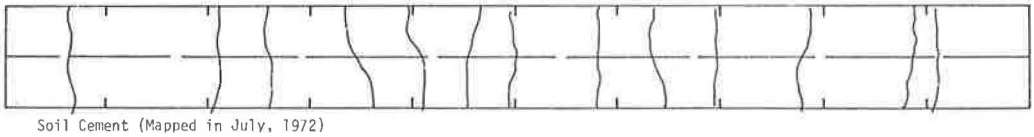


Soil Cement (Mapped in July 1972)

Figure 7. Cracking pattern of soil-cement base and superimposed pavement for experimental section with sugar additive.



Pavement (Mapped in June, 1973)



Soil Cement (Mapped in July, 1972)

Figure 8. Cracking pattern of soil-cement base and superimposed pavement for experimental section with Type II cement (same as control section).

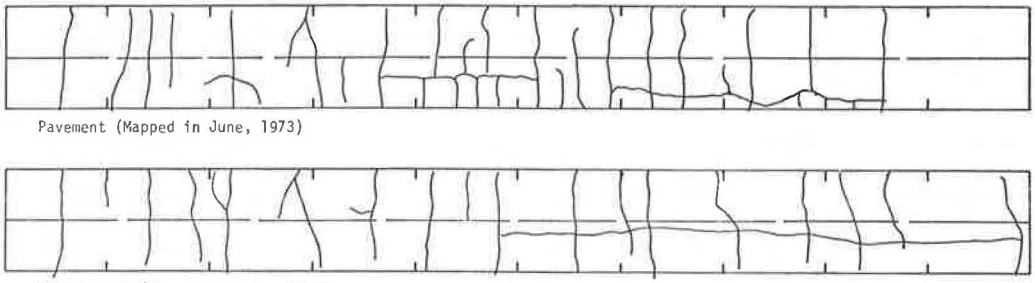


Figure 9. Cracking pattern of soil-cement base and superimposed pavement for experimental section with Type K expansive cement.

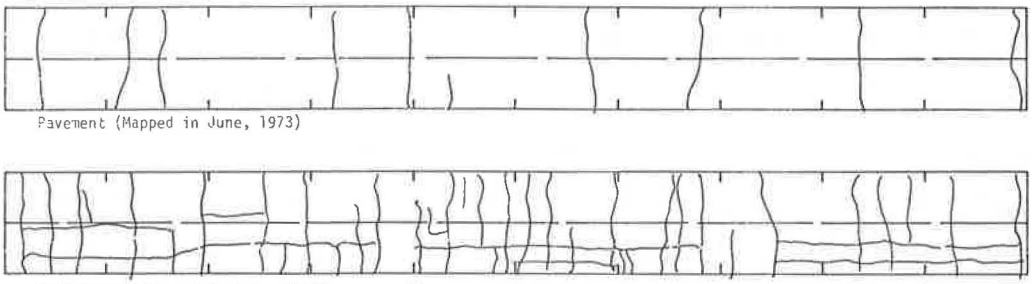


Figure 10. Cracking pattern of soil-cement base and superimposed pavement for experimental section with 7-day undisturbed curing period.

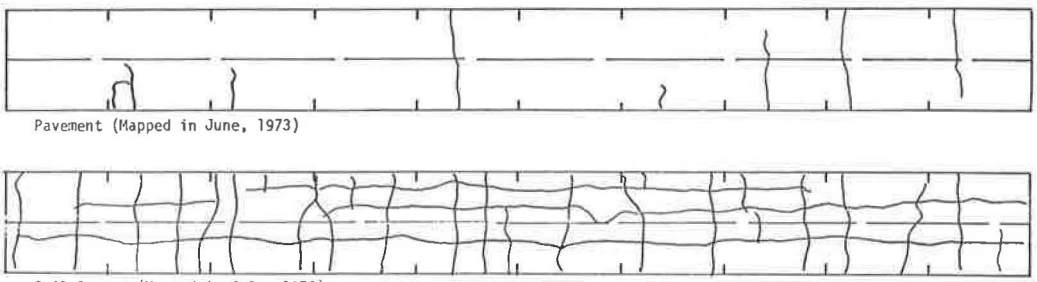


Figure 11. Cracking pattern of soil-cement base and superimposed pavement with artificial traffic.

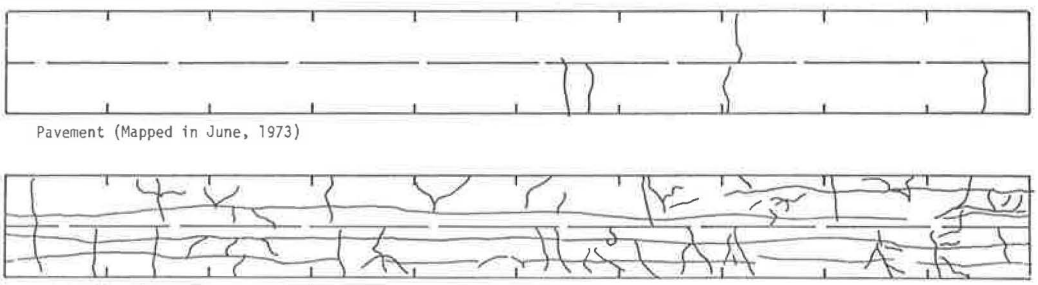


Figure 12. Cracking pattern of soil-cement base and superimposed pavement for experimental section with less cement content.

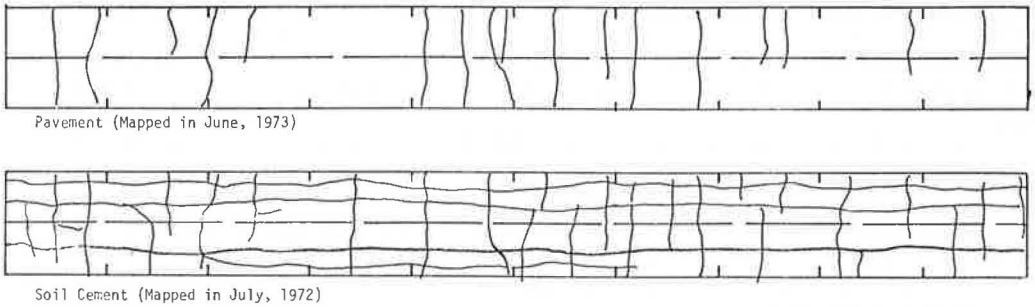


Figure 13. Cracking pattern of soil-cement base and superimposed pavement for experimental section with less cement and increased thickness.

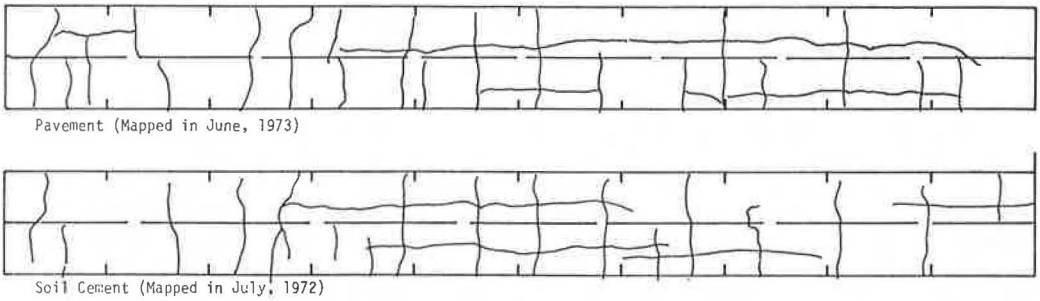


Table 5. Summary of results.

Section	Elapsed Time (min)	Field Moisture[a] (pcf)	Field Density[a] (pcf)	Penetration Resistance at 30 Hours (psi)	Field Cement Content (percent)	Core Strength (psi)	Deflection (mils)	Cracking Index on Soil-Cement (ft/ft^2)	Cracking Index on Pavement (ft/ft^2)
Control	75	-1	-2	6,000 to 7,000	3.7 to 10.7	199 to 549	1.434	0.119	0.102
Experimental									
Lime (two mixings)	105	-2	-2	5,000 to 7,000	—	—	1.680	0.237	0.031
Lime (one mixing)	55	-1	+2	5,000 to 5,500	—	—	1.635	0.072	0.127
Sugar	200	-2	-3	2,500 to 3,000	—	—	1.718	0.128	0.132
Type II cement (same as control)	85	-2	-1	6,000 to 7,000	—	—	1.480	0.095	0.104
Type K cement	90	-4	-1	6,000 to 7,000	—	—	1.538	0.257	0.061
7-day undisturbed curing	55	-1.5	-2	6,000 to 6,500	—	—	1.567	0.325	0.032
Artificial traffic	55	-2	-2	8,000 and above	—	—	1.345	0.227	0.021
Less cement	35	-3	+2	6,000 to 6,500	—	—	1.660	0.264	0.137
Less cement and increased thickness	50	-1	-1	6,000 to 6,500	—	—	1.670	0.153	0.166

Note: 1 pcf = 16.018 46 kg/m^3; 1 psi = 0.006 894 757 MPa; 1 ft/ft^2 = 3.2808 m/m^2.

[a]Deviations from specified density and optimum moisture.

material. Lime is also a retarding agent and when used in one mixing operation often creates wider cracks. However, when used in the two mixing operations, it creates more but finer cracks.

When expansive cement is used in the soil-cement mixture, it creates numerous hairline cracks on the soil-cement. Data obtained to date show that these cracks are not reflective.

The 7-day undisturbed curing section created about the same amount of cracks on the soil-cement as the control section, but these are also very fine cracks, and to date only a few cracks can be found on the pavement surface.

The section with artificial traffic created numerous hairline cracks on the soil-cement, and field survey indicated that these cracks were not reflective.

Sections using less cement are not desirable because they created larger cracks and most of them are reflective.

TENTATIVE CONCLUSIONS AND RECOMMENDATIONS

The present design criteria for the soil-cement mixture are valid and need no modifications. However, consideration should be given to adding a small percentage of lime to the soil-cement mixture when high clay contents (16 percent or more) are found on the base material. The benefit of lime additive is not conclusive from this study because the base material has only 14 percent clay content.

It is very important in soil-cement construction to have a uniform spreading of cement and to compact the soil-cement mixture as soon as possible to achieve the designed strength. Sugar is a good retarding agent but creates large cracks.

The crack survey indicates that it is almost impossible to keep the soil-cement from cracking under the field mass production operation. However, if the cracking can be formulated and retained as fine hairline cracks, it will not be reflective on the pavement surface. This is true even when the cracks are numerous. Therefore, research should be directed toward finding out how to keep the cracks small and numerous, rather than how to eliminate them.

Plans will be made in the next 2 years of observation to drill cores at the locations of the fine hairline cracks to study if the cracks are watertight and have zero or minimum growth. The undisturbed curing and artificial traffic sections have recorded numerous fine cracks on the soil-cement but only a small amount of cracks on the pavement surface. Providing a 7-day undisturbed curing practice is very expensive and inconvenient; therefore, it is recommended that the undisturbed curing requirement in the present specification be deleted and that construction traffic and necessary local traffic be allowed on the soil-cement during the 7-day period.

Based on these conclusions, the use of a lime additive (two mixings) and expansive cement should be incorporated in the design and construction of other projects so that their validity may be ascertained.

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

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DISCUSSION

Eddie Otte, National Institute for Road Research, Pretoria, South Africa

The efforts of the authors in preparing this report on a very well-designed and comprehensive field experiment on cement-treated bases are sincerely appreciated. Engineers engaged in this field of research are looking forward to further reports.

The remark on the unsatisfactory performance of the two-layer, soil-cement construction aroused additional interest. In South Africa this form of construction was, and is, extensively used, and its abandonment in Mississippi may influence its future use. The comments of the authors on the following questions would therefore be extremely helpful:

1. Why was the two-layer design abandoned?
2. On how many cases was the decision based? How frequently did soil-cement distress appear?
3. What was the form of the distress or failure that was observed?
4. There are numerous factors controlling the performance and failure of a soil-cement base. Why was the use of a two-layer construction isolated and chosen as the cause of the failure?
5. How was the lower layer cured? How could this have influenced the performance?
6. What was the extent to the bond between the two cement-treated layers? Did you observe any signs of slippage or horizontal movement between the two layers?

AUTHORS' CLOSURE

Otte's comments are very much appreciated. It is acknowledged that the reason why Mississippi abandoned the two-layer, soil-cement design should be discussed in greater detail. In an effort to be completely clear and to avoid repetition, we offer the following comments in answer to Otte's questions.

Generally, the reasons for abandoning the two-layer system are threefold. Because of the advancement in design of construction equipment, certain thicknesses of soil-cement design can now be constructed as a single (monolithic) layer rather than as two layers. Single-layer construction is much more economical than two-layer construction. A few two-layer construction projects (traveling plant mixing) experienced the type of distress shown in Figure 1, where either the top or the bottom layer resulted in a distinct shear type of failure. From the field excavation, it appears that when the top layer failed, it was under some compressive force and yielded in shear. The expansion and the resulting compressive stress may be due to the several cracks that extended deep into the soil-cement base. During the cold weather when the cracks were at their maximum width, foreign materials may have crept into these cracks and, subsequently, when the temperature rose, the soil-cement slabs could not expand freely, thereby subjecting the slab to a compressive force. Second, alternate shrinkage and expansion resulting from drying and wetting could also create compressive force attributable to the same mechanism.

In other areas where the bottom layer has undergone typical shear failure and the top layer has exhibited only a minor crack, compressive failure may have been caused by the expansion in the bottom layer at a weak point that is possibly associated with constructed joints. This expansion and that of the top layer occur because of the same reasons.

During the field investigation, considerable moisture was accumulated at the inter-

face between the top and bottom layers. That the bottom face of the top layer was poorly cemented was important. This caused the two 5-in. (127 mm) layers of soil-cement base to act separately as two layers rather than as one 10-in. (254 mm) base course to support the pavement. However, no sign of slippage or horizontal movement between the two layers was observed.

On a few two-layer projects that were constructed by the central plant mixing operation, many more cracks were observed than in the single-layer base course. On Miss-6 at the Oxford Bypass, which was constructed in 1965, near the University of Mississippi, both two-layer and single-layer designs were used. The two-layer portion was constructed with central plant mixing, and the single-layer portion was made with traveling plant mixing. Before the soil-cement base was covered with the bituminous pavement, the project engineer noticed that the two-layer portion had many more cracks than the single-layer portion (4). This observation was not documented; therefore, the authors specially requested the Department of Civil Engineering of the University of Mississippi to conduct field cracking surveys on the pavement. This survey (5) indicated that the two-layer section showed more transverse and longitudinal cracks than the single-layer section. The crack density (length of cracks per area) is also higher for the two-layer section than for the single-layer section. Results of this survey are given in Table 6. Figure 14 shows the general view of pavement surface of the single-layer section and Figure 15 shows the two-layer section.

Inasmuch as the two-layer section was constructed with the central plant mixing operation, there should be no problem in bonding the two layers. No sign of slippage or horizontal movement between the two layers was observed. If one assumes that the two layers were properly bonded and that they act as a monolithic layer, the hypothesis

Table 6. Crack survey, Miss-6, Oxford Bypass.

Pavement Type and Location	Total Length of Cracks[a] (ft)	Crack Density (ft/ft^2)	Number of Transverse Cracks[a]	Longitudinal Cracks, Ft per 100 Ft of Pavement
Two-layer, 400 ft east of railroad crossing, north lane	518	0.211	11	246
Two-layer, 300 ft east of railroad crossing, north lane	520	0.212	12	220
Two-layer, 100 ft east of second interchange from west end, south lane	580	0.237	14	250
Two-layer, 800 ft west of first interchange, north lane	510	0.208	12	226
Two-layer, 900 ft west of first interchange, north lane	420	0.171	11	125
Two-layer, 800 ft west of first interchange, south lane	515	0.210	12	215
One-layer, 1,000 ft east of Miss-7 crossing, south lane	400	0.163	9	185
One-layer, 200 ft eadt of Miss-7 bypass, south lane	330	0.134	8	110

[a]Per pavement section, 100 ft long; 24 ft, 6 in. wide.

Figure 14. Pavement surface of single-layer section.

Figure 15. Pavement surface of two-layer section.

for the two-layer section to have more cracks is that the top and bottom layers created the usual soil-cement cracking pattern. The top layer not only produced the regular cracking pattern but also showed the reflective crackings that stemmed from the bottom layer.

For curing the layers, the specifications of the Mississippi State Highway Department require that each course, top or bottom, of the completed cement-treated material be covered with a bituminous curing seal. The curing seal should be applied as soon as possible. The entire surface should be kept continuously moist until the curing seal is applied. The curing seal used should consist of a rapid or medium curing cut-back asphalt (grade as designated by the project engineer), which is applied at a minimum rate of 0.2 gal/yd^2 (0.9 litres/m^2). The seasonal limitation for placement of prime coat does not apply to use of bituminous material as a curing seal.

The asphalt curing seal applied on any course should be continuously maintained intact and applied as many times as necessary during the 7-day curing period. We did not make any statement about the curing in the paper and do not believe that the curing method Mississippi used had any influence on the performance of the soil-cement base course.

We realize there are numerous factors controlling the performance and failure of a soil-cement base. Mississippi stopped using the two-layer design as a result of the unsatisfactory performance of several two-layer design projects. However, the two-layer design and construction practice, which involves relatively thin layers, was never isolated or chosen as the only cause for soil-cement distress.

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