Long-Term Performance of Flexible Pavements Located on Cement-Treated Soils

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Long-term performance of flexible pavements located on cement-treated soils and the longevity of soil-cement subgrades are examined at sections of four highway routes. Ages of the soil-cement subgrades range from 6 to 30 years. Field and laboratory studies were conducted at each section. Generally, the soil-cement subgrades were non-plastic and were classified as SM, or sandy silt, according to the Unified Soil Classification System, although the classification of the untreated soil subgrades located below the treated layers ranged from CL (clay) to GC (clayey gravel). Plasticity index of the untreated soils ranged from non-plastic to 44 percent. Generally, the untreated soils were moderately plastic. In situ bearing ratios of the soil-cement subgrades were generally very large. Based on a percentile test curve, the in situ bearing ratios of the cement-treated subgrades at the 90th and 50th percent test values were about 24 and 90, respectively. Based on overlay histories of the routes, flexible pavements located on the soil-cement subgrades have performed well. In the older sections, overlays had been constructed every 11 to 14 years. Use of cement to construct stabilized subgrades represents a good design alternative when compared with other stabilizing methods and other design alternatives.

Although cement has been used in past years as a chemical admixture to improve bearing strengths of highway soil subgrades, there is little published information concerning the long-term bearing strengths of cement-treated soils and the long-term performances of flexible pavements located on the cement-treated soils. Roberts (*1*) reported that in 1938 the Oklahoma Highway Department investigated the use of cement-modified subgrades by constructing 7 mi of test sections along US-62. Plasticity index of the clayey subgrade soil was reduced from 39 to 13 percent at the time of construction. Plasticity indices of the cement-treated subgrade after 45 years of service ranged from non-plastic to 13 percent. Roberts indicated that the pavements placed on the treated subgrades performed well during the 45 years of service. McGhee (*2*) reported on the use of cement-treated subgrades in Virginia and the long-term performance of pavements located on the treated subgrades. A major conclusion was that pavements constructed on cement-treated subgrades were much more resistant to rutting and other distortions when compared with most pavements 10 or more years old. No long-term strength data are shown in the reports by Roberts or McGhee. Laboratory tests performed on remolded mixtures of soils and cement generally exhibit large shear strengths in excess of 700 kPa (*3*).

To determine the long-term strengths and field durability of cement-treated subgrades and to examine the long-term performance of pavements constructed on cement-treated subgrades, four highway routes that have been in service for a number of years were selected. Two of the routes have been in service for some 30 years. Two sections of the third route have been in service for 9 and 14 years, respectively. Two sections of the fourth route have been in service for about 6 years. The findings of geotechnical field and laboratory studies performed at the four highway routes are summarized in this paper and the general performance of flexible pavements located on the soil-cement subgrades is described.

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TESTING PROCEDURES

Geotechnical field studies consisted of performing in situ bearing ratio tests on the top of the soil-cement subgrades and the top of the untreated soil subgrade located below the treated layer. These tests were performed through cored boreholes. Samples of the cement-treated subgrades and the untreated subgrades were obtained during the field testing for laboratory testing. Procedures of ASTM D 4429-84 were followed in performing the in situ bearing ratio tests. The reactive force necessary to push the penetrating rod was developed by jacking against the frame of a drill rig. Load and deflection measurements were obtained from a calibrated load ring and deflection dial. Efforts to obtain thin-walled tube samples were unsuccessful because of the hardness of the cement-treated subgrades. Core specimens of the pavement and cement-treated subgrades were obtained at each site. Diameter of the cores was 15 cm. Measurements and visual inspections of the core specimens were used to determine the actual in situ thickness of the flexible pavements and the number and thickness of overlays. Pavement performance was generally evaluated using overlay history (when available) and visual inspections.

Geotechnical laboratory tests were performed on the retrieved samples to determine the index properties of the cement-treated and untreated soils. Index tests included liquid limit (ASTM D 4318-84) and plastic limit (ASTM D 4318-84), particle-size analysis (ASTM D 422-63), specific gravity (ASTM D 854-83), and moisture content (ASTM D 2216-80). The materials were classified according to the Unified Soil Classification System (ASTM D 2487-85) and the American Association of State Highway and Transportation Officials' Classification System.

CASE STUDIES

KY-15

KY-15, located between Campton and Jackson, Kentucky, is about 32 km in length. The flexible pavement of this stretch of highway has been in service for approximately 30 years. The original design section consisted of 19.1 cm of flexible pavement, 15.2 cm of dense-graded limestone aggregate, and 15.2 cm of a soil-(portland) cement subgrade. Approximately 10 percent of cement (by dry unit weight) was mixed with the in situ soil subgrades. Details of the mixing operation were not available.

Index properties of the cement-treated and untreated subgrade soils at various locations are summarized in Table 1. At six locations, the untreated soils were classified as CL (clay) and A-4 to A-6. At other locations, the soils were classified as GC-GM (clayey gravel-silty gravel), and SC (clayey sand). Plasticity index of the untreated soils generally ranged from 6 to 16, although one specimen was nonplastic. Classification of the cement-treated soils was SM (sandy silt) and GM (silty gravel) (after 30 years) and either A-1, A-2, or A-4. All specimens of the treated layer were nonplastic. Hence there were noticeable differences in the index properties of the treated and untreated soils.

In situ bearing ratios of the cement-treated layer and underlying soil subgrade are compared in Figure 1. Except for the bearing ratio of 9.2 at Milepost 0.6, the bearing ratios of the cement-treated subgrades ranged from 54 to values greater than 100. In situ bearing ratios of the untreated soils ranged from 3.3 to 14.2. After 30 years, the in situ bearing ratios of the soil-cement were generally some 4 to 33 times greater than the untreated subgrade soils.

Total pavement thickness ranged from 47.6 cm to 63.5 cm, as shown in Figure 2. At 7 of 10 locations where the soil-cement subgrade was constructed, overlay thickness ranged from 3.2 to 6.4 cm. At 3 of the 10 locations, the overlay thickness ranged from 12.1 to 19.1 cm. Those three locations exist on a side-hill fill and apparently the fill settled over the 30-year period. It is conjectured that the large overlay thickness observed at those three locations was the result of adding leveling courses or patching

TABLE 1 Index Properties of Soil-Cement Layer and Untreated Soils of KY-11

Location (MP)	LL PL PI	No. 4	No. 10	No. 200	AASHTO	Unified	CBR
Soil-Cement Layer							
		Percent Passing			Classification		
0.6	non-plastic	87.2	77.5	44.3	A-4 (0)	SM	9.2
19.6	non-plastic	77.8	60.7	23.0	A-1-B (0)	SM	53.9
24.8	non-plastic	72.8	63.7	26.1	A-2-4 (0)	SM	>100
26.7	non-plastic	55.6	45.6	21.3	A-1-B (0)	GM	>100
19.6	non-plastic	73.9	58.1	25.1	A-1-B (0)	SM	>100
20.6	non-plastic	72.4	57.5	19.9	A-1-B (0)	SM	>100
Untreated Soils							
0.6	26 20 6	56.2	53.5	32.0	A-2-4 (0)	GC-GM	9.2
*16.0	28 20 8	86.4	84.1	52.0	A-4 (0)	CL	6.8
*16.8	non-plastic	58.0	57.8	28.4	A-2-4 (0)	GM	11.5
19.6	26 17 9	91.9	86.0	62.1	A-4 (3)	CL	14.3
26.7	26 19 7	47.8	44.7	27.4	A-2-4	GC-GM	15.1
19.6	34 21 13	86.9	72.2	53.3	A-6 (4)	CL	14.2
20.6	29 19 10	96.0	84.2	59.5	A-4 (3)	CL	8.9
26.1	35 21 14	89.2	77.5	55.5	A-6 (5)	CL	8.0
26.3	25 16 9	96.7	93.7	36.3	A-4 (0)	SC	10.9
0.0	38 22 16	98.1	91.8	71.6	A-6 (10)	CL	3.3

* *No soil cement -- sandstone subgrade (untreated sections)* **Sections reconstructed*

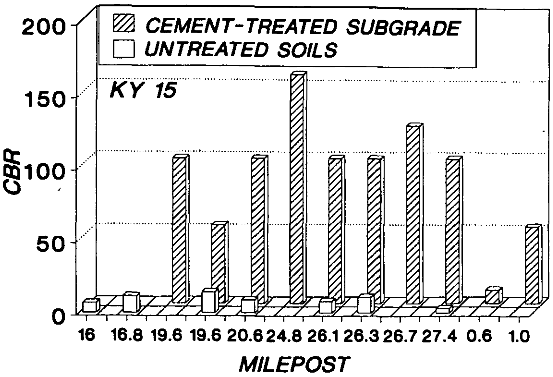

FIGURE 1 In situ bearing ratios of treated/untreated soils of KY-15.

when the overlays were constructed. At two locations (Mileposts 16 and 16.8), total pavement thickness ranged from 57.2 to 76.2 cm. Overlay thicknesses was 10.2 and 14 cm, respectively. At Milepost 16 the pavement was constructed on an untreated subgrade, whereas at Milepost 16.8 the pavement was placed on a subgrade built with a select rock material.

The time interval between overlay construction generally ranged from 11 to 15 years for the flexible pavements and averaged 12.2 years. On the basis of visual inspections made in 1990, only nominal rutting was observed. Hairline cracks were observed in the surface of the pavement. However, these did not affect the riding quality of the pavements. Annual daily traffic (ADT) of KY 15, as reported in 1989, was 5,000 vehicles per day (VPD). About 13 percent (650 VPD) of the ADT consisted of trucks, whereas 4 percent (200 VPD) of the ADT value consisted of coal trucks. Estimated equivalent single axle loads (ESAL)—converted from ADT values observed each year at different locations from 1986 to 1992—ranged from about 0.8 to 4.0 million and averaged about 2 million per year.

KY-79

KY-79 was relocated and reconstructed in 1959-1960 when a dam was constructed to create Rough River Lake. Reconstruction be-

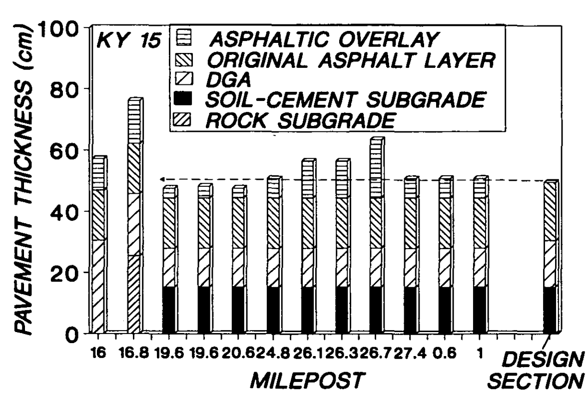

FIGURE 2 Thickness of the pavement at several locations of KY-15.

gan at the intersection of KY-110 (Milepost 18.1) in Grayson County and extended to the edge of the dam at Milepost 19.7. Reconstruction resumed at the Breckinridge county line (Milepost 0.0) and extended north to the intersection with KY-105 (Milepost 1.9) in Breckinridge County. Total length of reconstruction was 3.2 km, not including the length of roadway that traverses the dam (0.17 km). This flexible pavement and the cement-treated subgrade have been in service some 30 years.

The subgrade was constructed with a soil-cement-aggregate mixture designed by the U.S. Army Corps of Engineers. Proportions of the materials that were blended and construction specifications were not available. The thickness of the flexible pavement and stabilized subgrade, obtained from core measurements, is shown in Figure 3.

Total thickness of the pavements, as determined in 1991 and including the thickness of the treated layer, ranged from 25.4 cm to 35.6 cm. Thickness of the treated layers (Locations 2 through 7) ranged from 16.5 to 22.9 cm. Thickness of the flexible pavement, including overlays, ranged from 7 cm to 19.1 cm. A soil-cement layer was not used at Location 1 and 8 as shown in Figure 3. Locations 1 and 8 in Figure 3 are just beyond the limits of stabilization and are included for comparative purposes.

Index properties of the untreated and treated soils are shown in Table 2. The untreated soils were classified as CL, SM, and GC, and A-6, A-2-4, and A-2-7 at sampling locations. Plasticity indices of the untreated soils ranged from nonplastic to 44. Specimens of the cement-aggregate-soil subgrade obtained from three sampling sites were classified as SM and A-2-4 and A-1-B. The treated material was non-plastic. The untreated soils located below the treated layer of the section of roadway in Grayson County were non-plastic. Untreated soils below the treated layer of the section in Breckinridge County were generally plastic. The plasticity index ranged from 13 to 44 percent. In situ bearing ratios of the treated and untreated layers are shown in Table 3 and compared in Figure 4. In situ bearing ratios of the treated materials ranged from 62 to values in excess of 100. In situ bearing ratios of the untreated subgrade ranged from 2 to 7.1. The bearing ratios of the cement-treated materials were some 7 to 50 times the bearing ratios of the untreated soils. After about 30 years, the bearing strength of the cement-aggregate-soil layer was substantially greater than the bearing strength of the underlying untreated subgrade.

ADT, as measured in 1990, was 1,950 vehicles/day. About 140 vehicles/day, or about 7.2 percent of the total value of ADT, were classified as trucks. Values of ESAL, as observed in Grayson County at Milepost 18.1 to Milepost 1.9 in Breckinridge County, were 140,000 in 1989.

Overlays were constructed on the section in Breckinridge County in 1979 and 1989. Time intervals between overlay construction were about 10 years and 19 years, respectively. One overlay was constructed on the section in Grayson County in 1979, or about 19 years after construction. Reportedly an overlay was scheduled for 1991 or 1992, or about 14 years after the first overlay. Hence the time interval between overlays ranged from about 10 to 19 years and averaged about 15 years. As shown in Figure 3, the thickness of the asphaltic overlays added to the Breckinridge section in a 31-year period was substantially larger

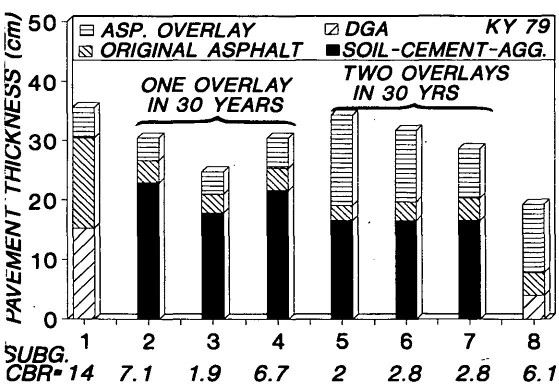

FIGURE 3 Pavement thickness of KY-79.

TABLE 2 Index Properties of Untreated Soils and Cement-Aggregate-Soil Subgrade of KY-79

Location (MP)	LL PL PI	Percent Passing No. 4	No. 10	No. 200	Classification AASHTO	Unified	CBR
Soil Cement-Aggregate							
Grayson Co. South							
18.2 (2)	non-plastic	84.7	81.9	16.1	A-2-4 (0)	SM	>100
18.9 (3)							>100
19.5 (4)							>100
Breckinridge Co. North							
0.6	non-plastic	73.9	56.4	22.2	A-1-B (0)	SM	61.7
1.4							>100
1.8	non-plastic				A-1-B (0)	SM	>100
Untreated							
Grayson Co. South							
18.2 (2)	non-plastic	98.8	94.0	29.2	A-2-4 (0)	SM	7.1
18.9 (3)							1.9
19.5 (4)							6.7
Breckinridge Co. North							
0.6	72 28 44	40.0	31.1	24.8	A-2-7 (0)	GC	2.0
1.4							2.8
1.8	36 23 13	82.9	71.0	59.3	A-6 (6)	CL	2.8

TABLE 3 Index Properties of Treated and Untreated Subgrades of US-23

Location (MP)	LL PL PI	Percent Passing No. 4	No. 10	No. 200	Classification AASHTO	Unified	CBR
US 23 Boyd Co. 1991							
Soil Cement (10%)							
4.05	non-plastic	76.4	66.0	30.9	A-2-4 (0)	SM	>100
4.5	37 31 6	74.2	56.9	24.2	A-1-B (0)	SM	>100
4.95	non-plastic	75.7	62.5	18.4	A-1-B (0)	SM	>100
7.5							123
7.55							88.4
7.65							>100
Untreated							
4.05	24 15 9	80.0	68.0	36.4	A-4 (0)	SC	13.6
4.5	35 18 17	82.9	62.7	42.7	A-6 (2)	SC	5.9
4.95							8.1
7.5							2.5
7.55							13.5
7.65	27 16 11	93.4	84.2	45.7			3.7
Rock Subgrade Section (Untreated)							
8.25							13.2
8.65	30 17 13	75.8	59.9	40.6	A-6 (2)	SC	15.0
8.95	26 17 9	57.6	43.9	24.5	A-2-4 (0)	GC	31.0
8.98							33.6
9.00							190.9
9.00	27 18 9	62.8	59.1	44.5	A-4 (1)	GC	40.0

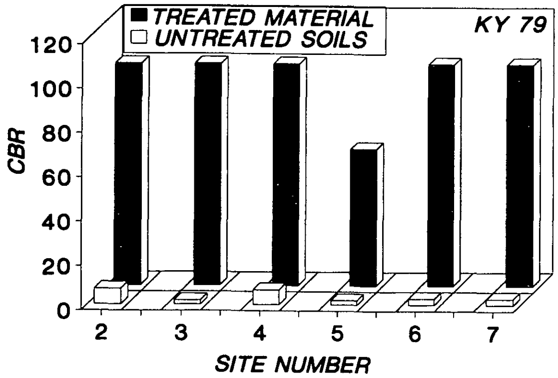

FIGURE 4 In situ bearing ratios of soil-cement-aggregate layer and untreated soils.

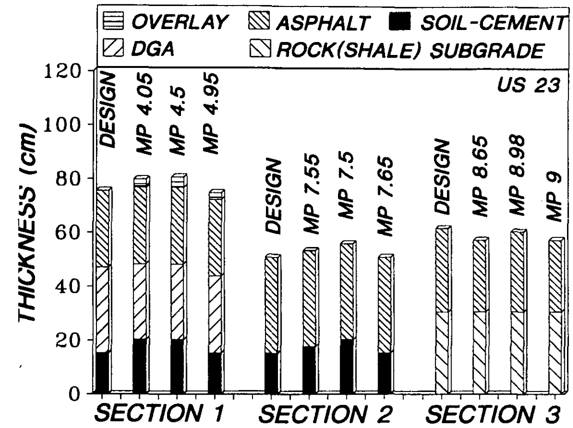

FIGURE 5 Pavement thickness of US-23 at different locations.

than the thickness added to the Grayson section. In the former case, the overlay thickness ranged from 3.8 to 5.1 cm, whereas in the latter case the overlay thickness ranged from 8.3 to 15.2 cm. As shown in Figure 4, bearing ratios of the untreated soils located below the cement-treated materials of the Breckinridge section ranged from 2 to 2.8. Bearing ratios of the untreated soils of the Grayson section ranged from about 2 to 7. Generally, the bearing ratios of the untreated soils of the Grayson section were greater than those of the Breckinridge section.

US-23

US-23 in Boyd County, Kentucky, was reconstructed in the late 1970s. Two sections containing cement-treated soil subgrades were included in the reconstruction. The first section, extending from Station 837+00 to 916+50 (2.4 km), was reconstructed in 1977–1978 and has been in service about 14 years. The original design cross section consisted of 28.6 cm of flexible pavement, 31.8 cm of dense graded (limestone) aggregate, and 15.2 cm of soil-cement. Total thickness of the pavement is 60.3 cm. When the soil-cement layer is included, the thickness is 75.53 cm. Observed thickness obtained from core specimens in 1990 is compared with the original design thickness in Figure 5. The second section, which extends from Station 916+50 to 1040+75 (3.9 km), was completed in 1984 and has been in service about 9 years. The design cross section consisted of 35.6 cm of asphaltic pavement and 15.2 cm of soil-cement. As shown in Figure 5, the actual thickness of flexible pavement at three locations ranged from about 27.9 cm to 28.6 cm. Thickness of the soil-cement layer ranges from 15.2 to 20.3 cm. This section contained no drainage layer. The top 15.2 cm of the soil subgrades of Sections 1 and 2 were mixed with 10 percent portland cement. The third section extends from Station 1040+75 to 1151+36 and the design cross section consisted of 31.1 cm of asphaltic pavement resting on a rock subgrade. This section was included for comparative purposes. It was completed in 1985 and has been in service for about 8 years. Actual thickness of flexible pavement at three locations was 29.8, 26.7, and 26.7 cm.

Index properties of the cement-treated subgrades and untreated soil subgrades of Sections 1 and 2 are shown in the top portion of Table 3. The untreated materials were classified as SC and A-4 and A-6. The cement-treated subgrades were classified as SM and A-1-B and A-2-4. Plasticity index of the soil-cement materials ranged from non-plastic to 6 percent. Plasticity index of the untreated soils ranged from 9 to 17 percent. The rock subgrade materials were classified as SC or GC and ranged from A-2 to A-6. Plasticity indices ranged from 9 to 13.

In situ bearing ratios (Figure 6) of the soil-cement subgrades were exceedingly large and ranged from 88 to values in excess of 100. In situ bearing ratios of the untreated soils of Sections 1 and 2 ranged from 2.5 to 13.6. In situ bearing ratios of the rock subgrade of Section 3 ranged from 13.2 to 191. Excluding the latter value, the bearing ratios generally ranged from 13.2 to 40. Bearing ratios of the soil-cement subgrades are several times greater than the untreated subgrades located below the treated layers and the rock subgrades of Section 3.

Based on core measurements, one overlay has been constructed on the pavement of Section 1 during its service period of about 14 years. Overlay thickness range from about 2.54 to 4.11 cm, as shown in Figure 4. No overlays have been constructed on Sections 2 and 3 during their service periods of about 9 and 8 years, respectively. ADT on the three sections, as obtained in 1989, is 8,890 VPD. About 3,645 VPD, or 41 percent, of the total ADT, or 2,578 VPD/day, were classified as coal trucks. Based on con-

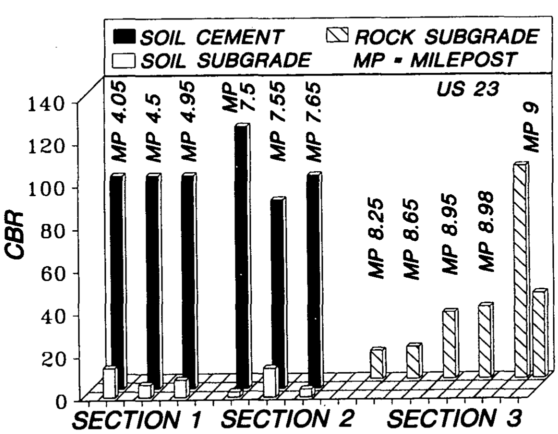

FIGURE 6 In situ bearing ratios of treated and untreated materials of sections of US-23.

verted values of ADT and percentage of trucks, the estimated ESAL value is 16.2 million for 1989, as observed between Mileposts 4 and 9. Between 1985 and 1991, the average ESAL was 7.2 million, as observed at seven different locations between milepost 0.1 and 13.2. Although these sections carry a large volume of truck traffic, the three sections have performed reasonably well.

KY-11

Portions of KY-11 were realigned and reconstructed in 1986-1987. The route is located about 11.7 km north of Beattyville, Kentucky. Total length of the reconstructed route is 9.6 km. The reconstructed route starts at Station 260+00 and ends at Station 576+50. Originally the pavement was to consist of 19.1 cm of asphaltic pavement and 43.2 cm of dense-graded limestone aggregate. A second option consisted of stabilizing the top 30.5 cm of subgrade with portland cement for the entire route. However, the final plan, which was implemented by a change order, consisted of dividing the entire length of the roadway subgrade into sections and treating each subgrade section with different chemical admixtures. Chemical admixtures used in the different subgrade sections consisted of hydrated lime, multicone kiln dust (byproduct), a byproduct obtained from an atmospheric fluidized bed combustion process, and portland cement (Type IP). Two sections of the subgrade were treated with cement. The first section extends from Station 317+00 to 348+00 (0.94 km) and the second section extends from Station 429+00 to 522+00 (2.82 km). The subgrade soils of the first section were mixed with 10 percent cement and the soils of the second section were mixed with 7 percent cement. The pavements of the two sections consisted of 15.2 cm of asphaltic concrete and 12.7 cm of dense-graded limestone aggregate. To provide some basis for comparison, a section of the subgrade of reconstructed Route 11 was not treated. This section of the roadway extends from Station 522+00 to Station 532+00 (0.3 km) and consisted 27.9 cm of asphaltic concrete and of 12.7 cm of crushed stone.

Geology of the route consisted of interbedded layers of shales, sandstones, siltstones, and coal. The residual soils along the corridor are derivatives of those materials. Liquid and plasticity index of 25 corridor samples obtained before construction at approximately 152.4-m intervals along the route (Station 264 to 484) generally were classified as CL (clay) and ML-CL (silt-clay).

At the 90th percentile test value of the 25 corridor samples, the liquid limit and plasticity index were 30 and 8, respectively, whereas the liquid limit and plasticity index were 34 and 12 percent at the 50th percentile test value, respectively. Residual soils used to construct the subgrade were stockpiled at three locations

TABLE 4 Index Properties of Treated and Untreated Soils of KY-11

CEMENT-TREATED SOIL							
1991	LL PL PI	Percent Passing			Classification		CBR
		No. 4	No. 10	No. 200	AASHTO	Unified	
319+20*	non-plastic	87.4	68.4	21.3	A-1-B (0)	SM	248
433+75**	37 28 9	87.2	71.4	41.0	A-4 (1)	SM	133
463+00							
1989							
321+50*	36 20 10	100.0	96.9	52.7	A-4 (3)	CL	21.2
333+90*	36 29 7	96.3	90.9	51.5	A-4 (2)	ML	
334+12*	44 37 7	97.3	92.6	37.1	A-5 (0)	SM	21.7
480+00**	non-plastic	97.1	95.9	48.6	A-4 (0)	SM	18.8
480+10**							10.5
433+15*8							5.8
MP 14**							18.8
273+00***							
354+00***							
574+00***							
UNTREATED SOIL							
319+20*	28 22 16	82.6	68.7	52.8	A-6 (5)	CL	9.0
433.75**							
463+00	42 23 19	95.4	83.4	72.8	A-7-6 (13)	CL	8.0
1989							
321+50*							
333+90*							
334+12*							
480+00**							
480+10**							
433+15**							
MP 14**							
273+00***	39 25 14	100	91.2	74.0	A-6 (10)	CL	
354+00***	43 28 15	100	92.4	73.0	A-7-6 (11)	CL	
574+00***	36 24 12	100	89.7	70.0	A-6 (8)	CL	

*10%
**7%
*** Stockpiles 1, 2, and 3

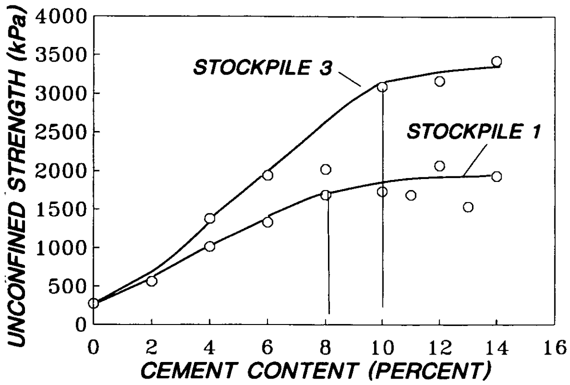

FIGURE 7 Optimum percentage of cement.

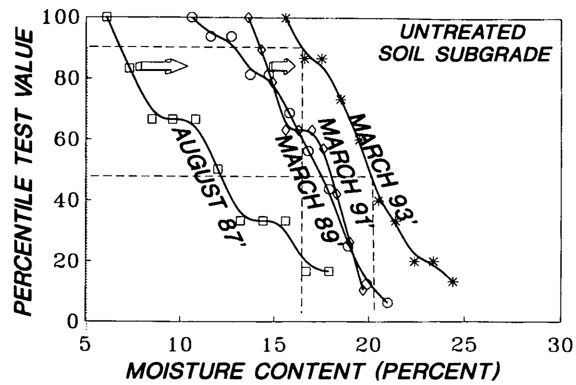

FIGURE 9 Moisture content of KY-11 untreated soil subgrades during a 5.5-year period.

(Stations 233+00, 354+00, and 574+00), as shown in Table 4, along the route. Samples obtained from these stockpiles were classified as CL. Plasticity index ranged from 12 to 15 percent.

Optimum percentage of cement was determined following procedures described by Hopkins et al. (*4*) and Hopkins and Beckham (*5*). In this approach, different percentages of cement were mixed with the soil and compacted to a known volume, dry unit weight, and moisture content. After aging the specimens in sealed containers for 7 days, unconfined triaxial compression tests are performed. The optimum percentage of cement is the point at which no increase occurs in the unconfined compressive strength as the percentage of cement increases. Two soil-cement series of unconfined compressive tests were performed on soils from stockpiles located at Stations 273+00 and 574+00. Because the maximum dry density and optimum moisture content of treated and untreated soils were essentially the same, all unconfined compressive specimens were molded to maximum dry density and optimum moisture content obtained from standard (ASTM D 698, Method *A*) compaction on untreated soils. Unconfined compressive strengths are shown in Figure 7 as a function of the percentage of cement. The optimum percentage of cement occurs at about 8 to 10.

In situ bearing ratios of the soil-cement layers, the soil subgrades located below the treated layers, and the soil subgrade of the untreated section were obtained over a period of about 6 years. The field-bearing ratios obtained for the two cement sections are shown in Figure 8. The lowest bearing ratio of the cement subgrades observed during the 6-year period was 7. Excluding that value, bearing ratios ranged from 11 to values in excess of 100 and averaged about 62. In situ bearing ratios observed during the 6-year period of the soil subgrade located below the cement-treated layers and the subgrade of the control section are shown in Figure 8. Bearing ratios ranged from 2 to 14 and averaged 5.7. Because the soils throughout the length of the reconstruction were essentially the same, the change in subgrade moisture content was measured during the study period. As shown in Figure 9, the moisture content of the untreated subgrade increased with increasing time. At the 90th and 50th percentile test values, the moisture contents increased from about 6.5 and 12 percent at the time of construction in 1987 to about 16.5 and 20 percent, respectively. With an increase in moisture content, there was a decrease in the bearing ratios, as shown in Figure 10. Whereas in situ bearing ratios of the soil subgrades during construction ranged from about 20 to 40, the in situ bearing ratios determined in March of 1993 ranged from 1 to 6. Percentile test values as a function of laboratory California bearing ratio (CBR) values of corridor soils and field CBR values of the untreated subgrade soils observed during the study period are shown in Figure 11.

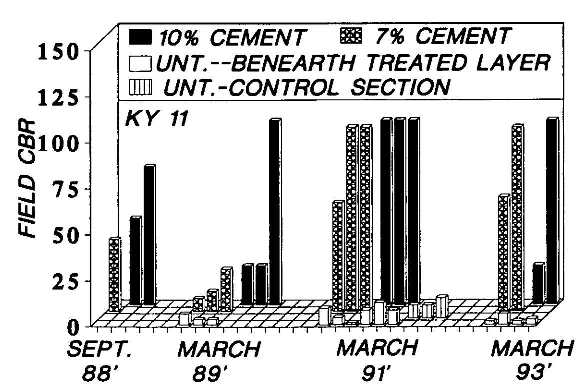

FIGURE 8 In situ bearing ratios of soil-cement layers and untreated soil subgrades of KY-11.

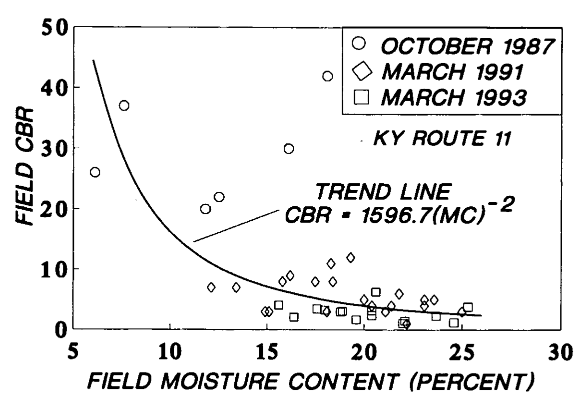

FIGURE 10 Relationship among in situ bearing ratios and field moisture contents measured at different times.

At the 90th percentile test value, the field and laboratory CBR is about 3. The field and laboratory CBR values at the 50th percentile test value are 6 and 7, respectively.

Rutting measurements of the pavement obtained in 1993 for all experimental sections are compared in Figure 12. Depth of rutting of pavements located on the cement-treated subgrades ranged from 0.00 to 0.15 cm after 6 years and was less than pavement rutting depths of the other experimental sections. Depth of rutting of the pavement in the control section ranged from 0.33 to 0.48 cm.

ADT of KY-11, as measured in 1990, was 2,200 VPD. About 13 percent of the ADT value was classified as trucks. Three percent of the trucks were classified as coal trucks. Estimated values of ESAL observed in 1988 and 1989 were 434,000 and 365,000, respectively.

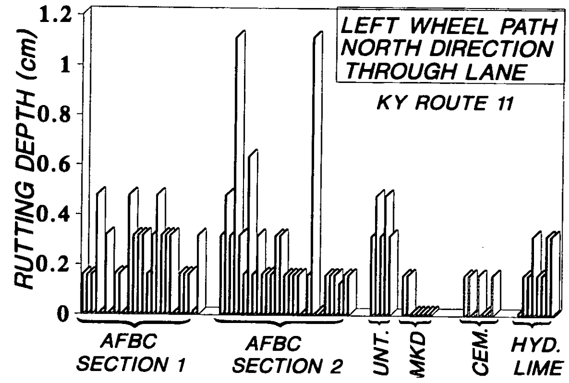

FIGURE 12 Rutting measurements obtained 5.5 years after construction.

SUMMARY AND CONCLUSIONS

Long-term in situ bearing ratios of cement-treated soil subgrades of four highway routes were measured. Ages of the routes and cement-treated subgrades ranged from 6 to 30 years. Thickness of the treated subgrades varied from 15.2 to 30.5 cm. Cement content used to treat the subgrades was 10 percent, although in one section of one route a cement content of 7 percent was used. Pavement thickness, which excludes the thickness of the cement-treated layers but includes thickness of overlays of the various sections of three of the four routes, ranged from 25.4 to 48.3 cm. Thickness of the fourth route was about 58.4 cm. Subgrade soils were classified as CL or ML-CL. Plasticity index of those soils was low to moderate. All specimens obtained from the various cement-treated layers during the study period were generally classified as SM, or silty sand.

Bearing strengths of the cement-treated subgrades were generally very large. The relationship among percentile test value and in situ bearing ratios of all treated layers of all sections is shown in Figure 13. At the 90th and 50th percentile test values, the bearing ratios are 24 and 90, respectively. These values compare well with bearing ratios of crushed stone. The strength of the cement-treated subgrades of the four routes was long lasting. Based on these data, the large bearing strengths of cement-treated soils could be expected to prevail throughout a 20-year design life that is typically assumed in flexible pavement design. Moreover, at two sections of one route, rutting depths of pavements placed on cement-treated subgrades were nominal after 6 years. On the basis of visual inspections of the other three routes, rutting was nominal.

Typically, flexible pavements constructed on the cement-treated subgrades had required an overlay about once every 11- to 14-year period. However, the overlays were generally thin; that is, less than about 6.4 cm. ADT of all routes included in the study ranged from about 2,130 to 8,000 VPD. Truck traffic ranged from about 800 to 3,200 vehicles/day.

Findings of this study demonstrate that the use of cement-treated subgrades is a valuable technique for stabilizing low-bearing soil subgrades and is a good design alternative when compared with other stabilizing methods and design alternatives.

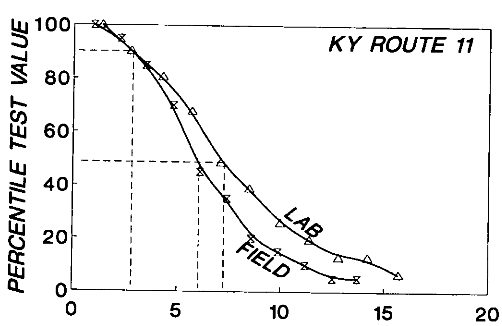

FIGURE 11 Comparison of laboratory California bearing ratio values of corridor soils and in situ bearing ratio values of KY-11 untreated subgrade soils.

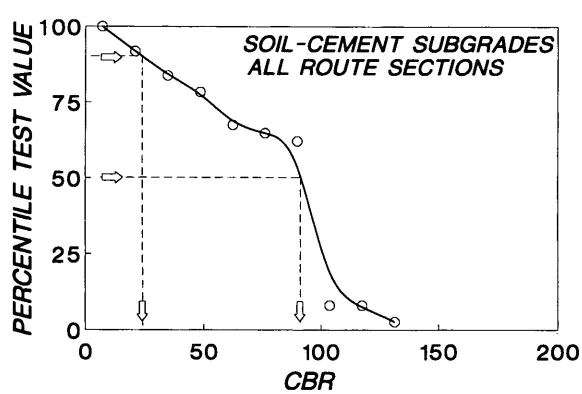

FIGURE 13 Percentile test value as a function of in situ California bearing ratio of soil-cement subgrades.

ACKNOWLEDGMENTS

The research reported herein was funded by the Federal Highway Administration and the Kentucky Transportation Cabinet through the University of Kentucky Research Foundation.

REFERENCES

1. Roberts, J. D. Performance of Cement-Modified Soils: A Follow-Up Report. In *Transportation Research Record 1089*, TRB, National Research Council, Washington, D.C., 1986.
2. McGhee, K. H. *Performance Design and Performance Studies* (Final Report on Phase A), Charlottesville Research Council, Charlottesville, Va., April 1972.
3. Terrell, R. L., J. A. Epps, E. J. Berenberg, J. K. Mitchell, and M. R. Marshall. *Soil Stabilization in Pavement Structures*, (A User's Manual, Vol. 2, Mixture Design Considerations), Federal Highway Administration, U.S. Department of Transportation, Oct. 1979.
4. Hopkins, T. C., D. Q. Hunsucker, and G. W. Sharpe. Highway Field Trials of Chemically Stabilized Soil Subgrades. In *Proc., 19th Ohio River Valley Soils Seminar*, Lexington, Ky., Oct. 1988.
5. Hopkins, T. C., and T. L. Beckham. Proposed Procedure for Compacting Laboratory Specimens for Physical Properties Testing. In *Proc., 10th Annual International Pittsburgh Coal Conference*, Pittsburgh, Pa., Sept. 1993.