Research Report
KTC-98-4

Use of Hydrated Lime Byproduct for Stabilization of Subgrade Soils

by

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INTRODUCTION

In January 1998, Minteck Resources requested that the Kentucky Transportation Center at the University of Kentucky perform a feasibility study to determine if a hydrated lime byproduct produced at the Carbide/Graphite facility in Calvet City, Kentucky can be used as a substitute for hydrated lime as a soil subgrade stabilizing agent. According to personnel of Carbide/Graphite Group, Incorporated, the byproduct contains a high percentage of hydrated lime.

BACKGROUND

Calcium hydroxide (hydrated lime), $Ca(OH)_2$, and calcium oxide (quick lime), CaO, are used as chemical admixtures to stabilize clay subgrades. Subgrades constructed by the Kentucky Transportation Cabinet are oftentimes stabilized with hydrated or quick lime when the California Bearing Ratio (CBR) value is six or less. This recommendation was made by the Geotechnology Section of The University of Kentucky Transportation Center as a result of a research study (1). The addition of hydrated or quick lime (typically five percent of dry weight) significantly improves the bearing capacity and compressive strength of clay subgrades. Hydrated lime reacts with clay particles and improves the engineering properties of clay. Past research has shown that hydrated lime tends to react better with high plasticity soils than low plasticity soils.

In September 1997, the Kentucky Transportation Center issued a report (2) summarizing the results of using the hydrated lime byproduct as a stabilizer for a soil sample submitted by the Carbide/Graphite Group, Inc. Engineering properties of the soil did not improve significantly with the addition of the hydrated lime byproduct. Because the soil had a low plasticity index (PI), a recommendation was made to test the Carbide/Graphite hydrated lime byproduct with soils with higher plasticity indices.

INITIAL TESTING

Three bulk samples collected previously by the Kentucky Transportation Center were used for the study. The samples are typical fine-grained residual soils found throughout Kentucky. Classification (liquid limit, plastic limit, specific gravity and particle size analysis) tests had been performed previously on the samples. The samples were air dried and processed to a very uniform texture. Moisture-density relations and bearing ratio tests were also performed previously on untreated samples and samples blended with five percent hydrated lime. Geotechnical properties of the samples are shown in Table 1. The three different soil types used in this study were obtained from sites located in Fayette, Hardin , and Campbell Counties, Kentucky. The three soil types were classified as A-7-6 (17), A-7-6 (22), A-7-6 (18), respectively. Plasticity indices of the samples ranged from 17 to 22.

Based on plasticity index (PI), only one of three different soil types (U. S. 31, W Hardin County) would qualify as a candidate for lime stabilization by the Kentucky Transportation Cabinet guidelines (3). This guideline states that hydrated lime is normally used for soil with a PI equal to or greater than

20. It further states that the appropriate chemical will be determined in accordance with the Federal

Table 1. Classification properties of untreated soil.

Sample Location	Limits			SG	Percent Passing				Classification	
	LL (%)	PL (%)	PI (%)		No.4 4.75 mm	No.10 2.00 mm	No. 200 .075 mm	.002 mm	USC	AASHTO
US 25 Fayette Co.	48	29	19	2.89	100.0	96.4	83.7	51	CL	A-7-6 (17)
US 31 W Hardin Co.	53	26	27	2.73	98.4	95.1	79.7	55	CH	A-7-6 (22)
KY 10 Campbell Co.	41	22	19	2.76	97.2	95.9	91.7	40	CL	A-7-6 (18)

Highway Administration's "Soil Stabilization Manual" (4). Those guidelines indicate that fine-grained soils classified by AASHTO criteria as A-4, A-5, A-6. and A-7 are usually more responsive to hydrated lime stabilization than coarse grained soils which classify as A-1, A-2. And A-3. Soils with PI's as low as 7 may be suitable for lime stabilization, according to these guidelines.

Previous testing by the Kentucky Transportation Center of the three soil types listed in Table 1 showed that unconfined compressive strengths and CBR strengths increased when five percent (by dry weight) of hydrated lime was mixed with the three soils. In those series of tests, the specimens were compacted to 95 percent of maximum dry density and at optimum moisture content, sealed in plastic containers to prevent moisture loss, and aged for seven days at room temperature.

In tests performed and reported herein in this study, a different aging procedure was used than the 7-day aging procedure. The specimens treated with hydrated lime and the hydrated lime byproduct produced at the Calvert City facility, were compacted, sealed, and cured in plastic containers for 48 hours at 49° C (120°F) in accordance with procedures used and specified by the Kentucky Transportation Cabinet's "Subgrade Chemical Stabilization Test." (5). This procedure, which is routinely used by the Kentucky Transportation Cabinet, because it speeds up the testing time (2 days versus 7 days)..

LABORATORY TESTING

Moisture-Density Relations

Standard moisture-density relations tests (AASHTO T 99) (6) were performed on untreated samples and on the samples treated with five percent (dry weight) hydrated lime and the hydrated lime byproduct (referred to hereafter as CG hydrated lime) produced at the Calvert City facility. The

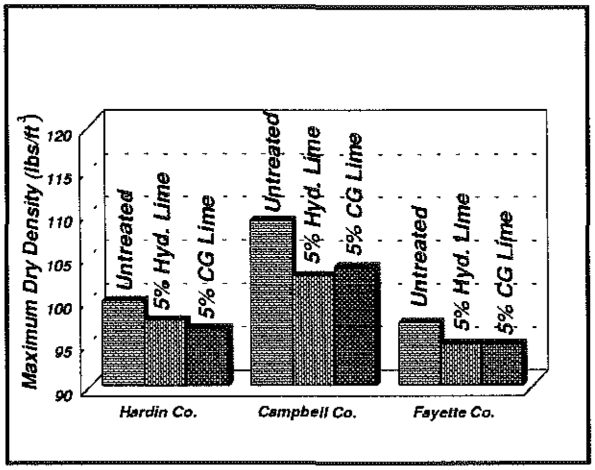

Figure 1. Changes in Maximum Dry Density with Hydrated Lime and CG Lime Byproduct

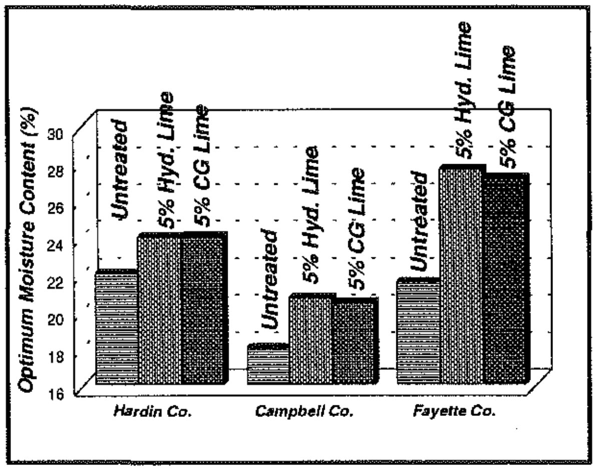

Figure 2. Changes in Optimum Moisture Content with Hydrated Lime and CG Lime Byproduct

samples mixed with hydrated lime (tested previously) and the CG hydrated lime byproduct were mixed to approximately five percent below optimum moisture content and sealed in a plastic container for one hour before compaction. The maximum dry density of compacted specimens decreased and optimum moisture content increased slightly when hydrated lime and the CG hydrated lime byproduct were added, as shown in Figures 1 and 2. The decrease of maximum dry density of the three soil types treated with five percent of hydrated lime ranged from 2.1 to 6.4 lbs/ft^3 (33.6 to 102.5 kg/m^3) and averaged about 3.7 lbs/ft^3 (59.3 kg/m^3). The decrease in maximum dry density of the three soil types treated with five percent of CG hydrated lime byproduct ranged from 2.4 to 5.4 lbs/ft^3 (38.4 to 86.5 kg/m^3) and averaged about 3.6 lbs/ft^3 (57.7 kg/m^3). The increase of the optimum moisture content of the three soil types ranged from 2.0 to 6.1 percent when hydrated lime was used while the increase of optimum moisture content ranged from 2.0 to 5.6 percent when the CG hydrated lime byproduct was used. These results indicated that reactions of the CG hydrated lime and the three soil types were very similar to the reactions of hydrated lime and the same three soil types.

Unconfined Compressive Strength Tests

As a means of observing increases in strengths when hydrated lime was added to the three soil types, a series of unconfined compressive strength tests were performed on remolded, or compacted, specimens mixed with different percentages of hydrated lime and the CG hydrated lime byproduct. Percentages of both byproducts used in this series of testing were zero, four, five, and six. The samples were recompacted near 95 percent of standard dry density and optimum moisture content, obtained from moisture-density relations tests, sealed in plastic containers, and aged for 48 hours at 49° C (120°F). This procedure (KM 64-520-95), as noted above, is used by Kentucky Transportation Cabinet, Division of Materials, Geotechnical Branch, to determine the optimum percentage of chemical stabilizer for highway subgrades (5). Unconfined compressive strength of

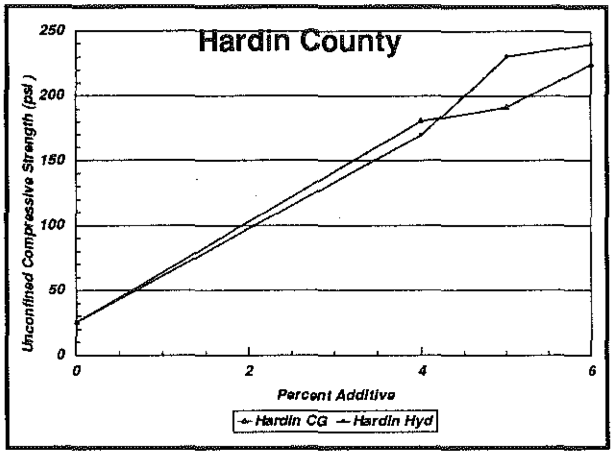

Figure 3. Change in Unconfined Compressive Strength with Increasing Percentages of Hydrated Lime and CG Lime Byproduct for Hardin County Sample

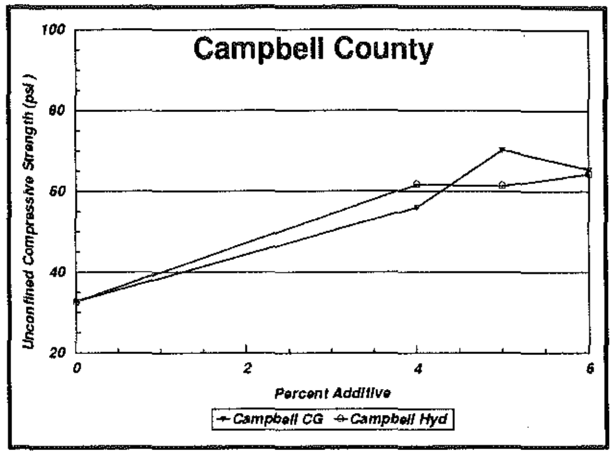

Figure 4. Change in Unconfined Compressive Strength with Increasing Percentages of Hydrated Lime and CG Lime Byproduct for Campbell County Sample

samples with zero percent additive, or untreated, is determined immediately after compaction. The recommended percentage of stabilizer is the percentage at which a 50 psi (345 kPa) increase occurs above the untreated soil strength, but with a compressive strength not less than 100 psi (690 kPa), or whichever is greater. As shown in Figure 3, the unconfined compressive strength of the Hardin County specimens increased from about 25.4 psi (175 kPa) for untreated specimens to 224.3 psi (1,546 kPa) for specimens mixed with six percent of the CG hydrated lime. The strength gain was about 214 psi (1,475 kPa).The unconfined compressive strength of the CG specimens was about nine times greater than the strength of the untreated samples. Similar results were obtained when hydrated lime was used. When six percent of hydrated lime was used, the unconfined compressive strength was 239.5 psi (1,651 kPa). At six percent, the strength of the CG specimens was about 94 percent of the strength of the hydrated lime specimens.

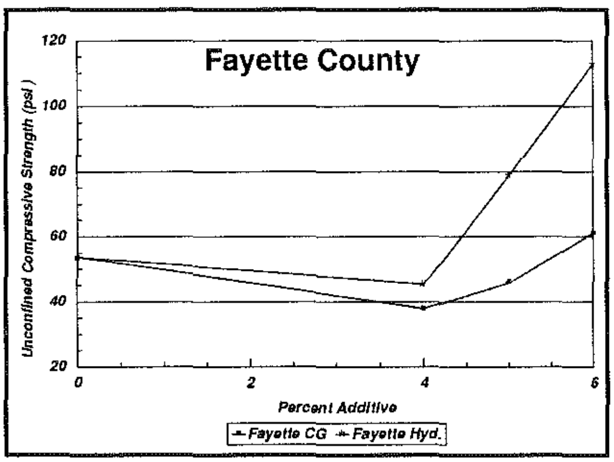

Figure 5. Change in Unconfined Compressive Strength with Increasing Percentages of Hydrated Lime and CG Lime Byproduct for Fayette County Sample

Unconfined compressive strength of the untreated Campbell County specimen was 32.6 psi (224 kPa), as shown in Figure 4. When six percent of the CG hydrated lime byproduct was used, the unconfined strength was 65.3 (450 kPa), or the strength nearly doubled. Similarly, the unconfined strength of specimens blended with six percent of hydrated lime was about 64.2 psi (442 kPa). The unconfined strength of the CG specimens at six percent were some 102 percent of the hydrated lime specimens.

Unconfined compressive strength of an untreated specimen of the sample from Fayette County strength was 53.6 psi (369 kPa). At six percent of hydrated lime, the unconfined strength increased to a value of about 112.4 psi (775 kPa). However, the unconfined compressive strength of specimens mixed with six percent of the CG hydrated lime was about 61 psi (421 kPa). A slight increase occurred. The strength of the CG hydrated lime specimen was only 54 percent of the hydrated lime specimen. At four percent, the strengths of both hydrated lime and the CG hydrated lime specimens were similar as shown in Figure 5.

Bearing Ratio Tests.

California Bearing Ratio (CBR) tests were performed on recompacted specimens of the following mixtures:

- Soil only
- Soil and 5% hydrated lime
- Soil and 5% CG hydrated lime byproduct

Two series of AASHTO CBR tests were performed. In the first series, CBR tests were performed in accordance with AASHTO T-193 (6) procedures. The samples were compacted to the desired density and moisture content (95 % of standard maximum dry density and optimum moisture content) and allowed to soak in water for a period of 96 hours (4 days). Tests in both series were performed on the untreated soil specimens and with soil specimens blended with five percent hydrated lime and the CG hydrated lime byproduct. The second series of specimens were compacted and allowed to soak in water for an extended period of time (8 days for untreated and 21 days for treated samples). This second series of tests were performed for two reasons :

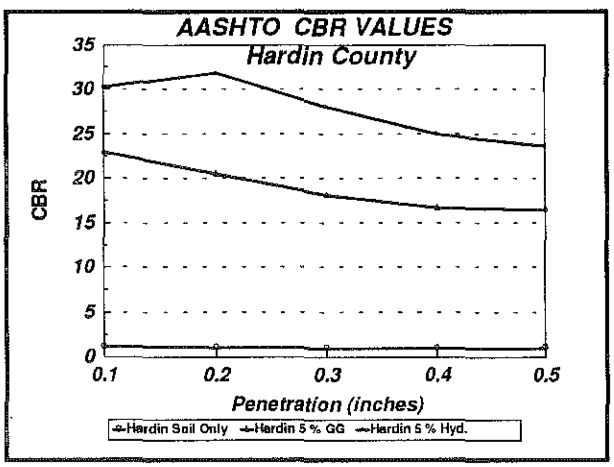

Figure 6. Standard CBR Values for Hardin County Sample

1. To observe potential long-term swelling (past experience has shown that some byproducts containing lime and sulfur compounds produce swelling reactions when exposed to water for periods of time exceeding 100 hours), and

2. To determine if an extended period of exposure to moisture affects bearing capacity of CG hydrated lime byproduct soil specimens.

Standard CBR Tests

Values of CBR of the three untreated soil types were very low and were less than 2. However, the addition of the CG hydrated lime and hydrated lime significantly improved the bearing strengths of the soils, as shown in Figures 6 through 8. In those figures, the variations of CBR values with depth of penetration are illustrated. All results of standard CBR testing are summarized in Table 2. The addition of hydrated lime and CG hydrated lime byproduct increased the CBR values for all three soil types. The untreated, standard CBR value of the Hardin County sample at 0.1 inch (2.5 mm) penetration was 1. Normally, the CBR value at 0.1-inch penetration is reported. When five percent (by dry weight) of hydrated lime was added to this soil, the CBR value increased to 30.3 at 0.1-inch penetration. Adding five percent of CG hydrated lime increased the CBR to 22.9 at 0.1-inch penetration. The CG hydrated lime CBR was about 76 percent of the hydrated lime CBR.

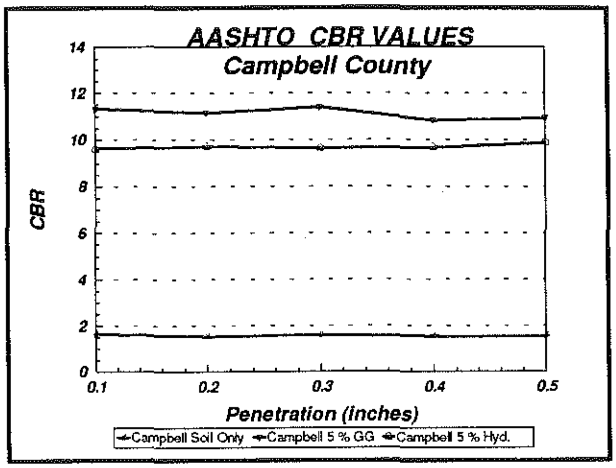

Figure 7. Standard CBR Values for Campbell County Sample

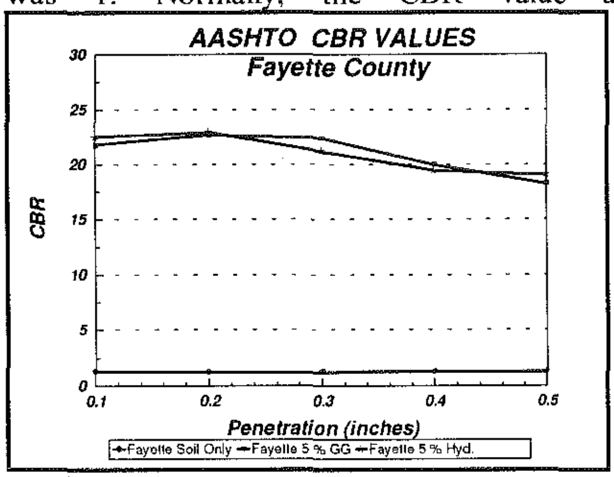

Figure 8. Standard CBR Values for Fayette County Sample

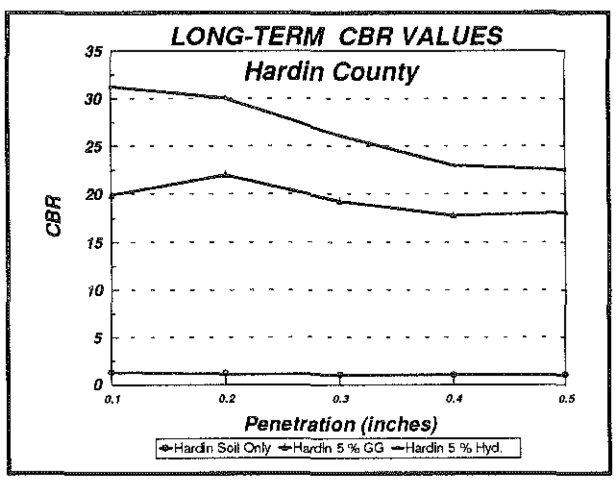

Figure 9. Long-Term CBR Values for Hardin County Sample

At a penetration of 0.- inch, the value of CBR of the Campbell County soil was only 1.7. The addition of five percent hydrated lime increased the CBR value to 9.6. With the addition of CG hydrated lime, the CBR value increased to 11.3. In this case, the CG CBR was some 118 percent of the hydrated lime CBR.

At a penetration of 0.1-inch, the value of CBR of the Fayette County soil was 1.3. The addition of five percent hydrated lime increased the CBR values to 22.5. With the addition of CG hydrated lime, the CBR value increased to 21.8. In this case the CG hydrated lime CBR was about 97 percent of the hydrated CBR.

Long-Term CBR-Swell Tests

Long-Term CBR Values

To determine if significant swelling occurs using

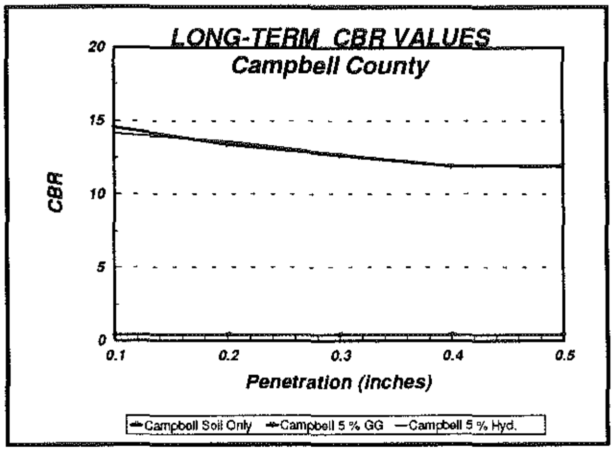

Figure 10. Long-Term CBR Values for Campbell County Sample

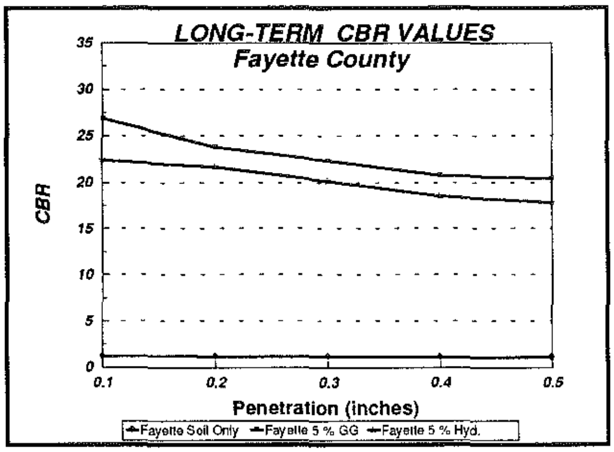

Figure 11. Long-Term CBR Values for Fayette County Sample

the CG hydrated lime byproduct as a chemical admixture and to determine if prolonged exposure to moisture had any effects on bearing capacity, CBR tests on treated samples were performed using a long-term soaking period of 21 days. CBR values of specimens soaked for 21 days were equal to or higher than standard test values of CBR obtained from specimens soaked for 4 days. Values of CBR specimens soaked for 21-day soaking period are shown in Table 3 and Figures 9, 10, and 11.

At a penetration of 0.1-inch (2.5-mm) and using five percent of the CG hydrated lime, CBR values of the Hardin, Campbell, and Fayette County soil specimens were 19.9, 14.6, and 26.9, respectively, as shown in Table 4. For the shorter soaking period of 4 days, the CBR values were 22.9, 11.3, and 21.8, for the three specimens, respectively. The longer soaking period did not significantly affect the CBR values. CBR values of the untreated soil specimens soaked for 8 days were either equal to or less than CBR values of untreated specimens soaked for only 4 days. CBR values of untreated specimens ranged from 0.4 to 1.7. CBR values at 0.1 inch (2.5-mm) penetration of specimens treated with five percent hydrated lime and soaked for 21 days were 31.2, 14.1, and 22.3, respectively, for the Hardin, Campbell and Fayette Counties samples. CBR values for specimens soaked for 4 days were 30.3, 9.6, and 22.5, respectively. In both cases, the CG hydrated and the hydrated lime increased bearing ratios significantly. Generally, CBR values of the treated specimens were some five times, or greater, than CBR values of untreated specimens.

Swelling Potential

The magnitude of swell of the untreated soil samples, measured during the extended soaking period, was about three to four percent. Swelling magnitudes of this order have the potential to damage pavements. When five percent of CG hydrated lime and hydrated lime were blended with the three different soil types, the magnitudes of long-term swell decreased to values of 0.5 percent or less. Long-term swells of the soil samples and soil lime mixtures are shown in Figures 12, 13, and 14. Approximately 10-lb. (4.5-kg) surcharge mass was placed on all CBR and swell samples.

Table 2. Standard CBR Values of Soil and Soil-Lime Mixtures - - 4 day soaking period

Sample ID	CBR Value at Penetration of:				
	0.1-in. (2.5-mm)	0.2-in. (5.1-mm)	0.3-in. (7.6-mm)	0.4-in. (10.2-mm)	0.5-in. (12.7-mm)
Hardin Soil Only	1.2	1.06	1.0	1.0	1.0
Hardin 5% Hydrated Lime	30.3	31.8	28.0	25.0	23.6
Hardin 5% CG Lime	22.9	20.5	18.1	16.6	16.5
Campbell Soil Only	1.7	1.5	1.6	1.5	1.5
Campbell 5% Hydrated Lime	9.6	9.7	9.6	9.7	9.9
Campbell 5% CG Lime	11.3	11.2	11.4	10.8	10.9
Fayette Soil Only	1.3	1.2	1.2	1.2	1.2
Fayette 5% Hydrated Lime	22.5	22.9	21.2	19.4	19.0
Fayette 5% CG Lime	21.8	22.6	22.4	19.2	18.0

Table 3. Long-Term CBR Values of Soil and Soil-Lime Mixtures extended soaking period

Sample ID	CBR Value at Penetration of:				
	0.1-in. (2.5-mm)	0.2-in. (5.1-mm)	0.3-in. (7.6-mm)	0.4-in. (10.2-mm)	0.5-in. (12.7-mm)
Hardin Soil Only	1.3	1.1	1.0	1.0	1.0
Hardin 5% Hydrated Lime	31.2	30.0	26.1	23.0	22.6
Hardin 5% CG Lime	19.9	22.0	19.2	17.7	18.1
Campbell Soil Only	0.4	0.4	0.4	0.4	0.4
Campbell 5% Hydrated Lime	14.1	13.6	12.7	11.9	11.8
Campbell 5% CG Lime	14.6	13.4	12.6	11.9	11.9
Fayette Soil Only	1.2	1.2	1.1	1.1	1.1
Fayette 5% Hydrated Lime	22.3	21.6	20.1	18.5	17.8
Fayette 5% CG Lime	26.9	23.7	22.3	20.7	20.4

Table 4. Comparison of CBR Values at 0.1-inch (2.5 mm) Penetration for 4-day and Extended Soaking Periods

	Hardin	Campbell	Fayette
untreated 4- day	1.2	1.7	1.3
untreated 8-day	1.3	0.4	1.2
CG lime 4-day	22.9	11.3	21.8
CG lime 21-day	19.9	14.6	26.9
hydrated lime 4-day	30.3	9.6	22.5
hydrated lime 21-day	31.2	14.1	22.3

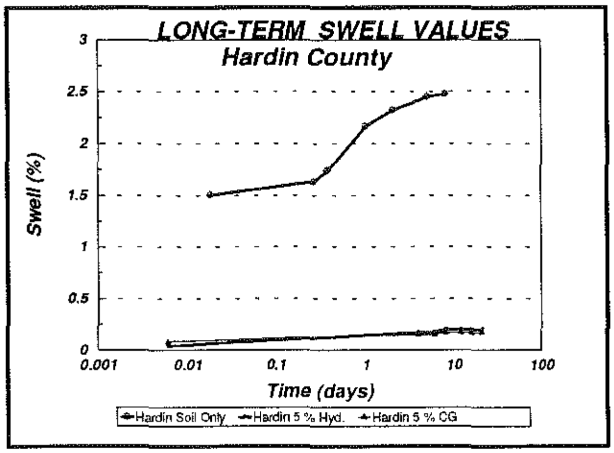

Figure 12. Long-Term Swells for Hardin County Sample

CONCLUSIONS

The addition of equal amounts of hydrated lime and CG hydrated lime byproduct from the Carbide Graphite facility yielded similar increases in unconfined compressive strengths for the samples from Hardin and Campbell Counties. Unconfined compressive strength (112.7 psi, 16.3 kPa) of the soil sample from Fayette County, treated with six percent hydrated lime, was greater than the unconfined compressive strength (61.0 psi, 8.8 kPa) of the same soil treated with six percent of the CG hydrated lime. However, at six percent, the unconfined strengths of both treated samples were greater than the unconfined strength (53.6 psi, 7.8 kPa) of the untreated Fayette County soil.

Increases in standard CBR values were very similar for the samples from Campbell and Fayette Counties. CBR values of the sample from Campbell County increased from less than two to about ten with the addition of five percent hydrated lime and about 11 with the addition of five percent of the CG hydrated lime byproduct. The CBR of the Fayette County sample increased from about one to approximately 20 with the addition of five percent hydrated lime. The same increases occurred when five percent of the CG hydrated lime from Carbide Graphite's facility was added. Standard CBR values of the Hardin County sample increased from about one to around 30 when five percent of hydrated lime was added and to approximately 20 when five percent lime of the CG hydrated lime was added. Although the increase was less when the CG lime byproduct was mixed with the Hardin County sample, the increase was still large enough to stabilize the soil.

Increases in long-term CBR values were very similar to increases observed when standard CBR tests

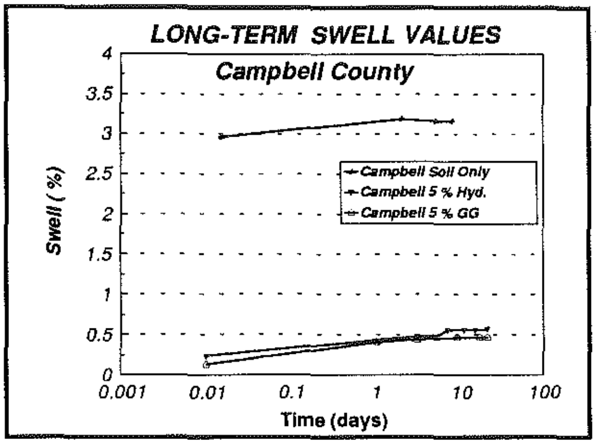

Figure 13. Long-Term Swells for Campbell County Sample

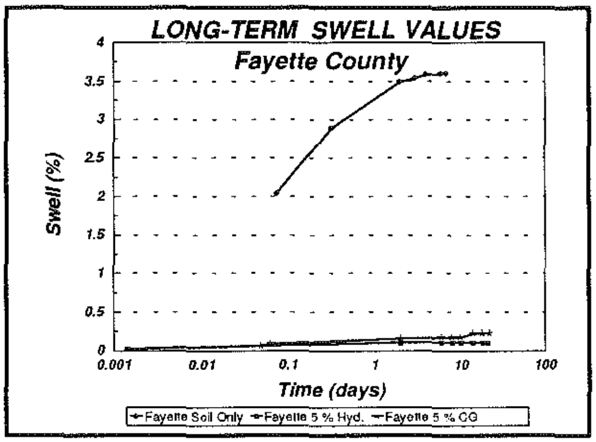

Figure 14. Long-Term Swells for Fayette County Sample

were performed, although the long-term CBR test specimens were exposed to water (soaked) for a greater period of time than the standard CBR test specimens. Swell magnitudes of the compacted untreated specimens of the three soil types ranged from 3 to 4 percent. With the addition of the CG hydrated lime, or hydrated lime, the swelling magnitudes of compacted specimens were reduced to values that were less than 0.5 percent. Hence, both the CG hydrated lime and hydrated lime reduced detrimental swell magnitudes of the three soil types tested in this study.

RECOMMENDATIONS

Based on unconfined compressive strength and CBR tests, the CG hydrated lime byproduct could be used as a stabilizer for the Hardin and Campbell Counties samples. Unconfined compressive strength tests of soil specimens mixed with five percent of the CG hydrated lime byproduct were lower than those with hydrated lime for the Fayette County sample. However, the strength did increase and with time, the increase should become greater based on the long-term CBR test. The as compacted unconfined compressive strength (near 95 percent of maximum dry density and optimum moisture content) will be larger than the long term strength of untreated samples exposed to moisture. Clay subgrades will swell and lose strength when exposed to moisture. Unconfined compressive strength will be significantly less for untreated samples exposed to moisture. However, CBR tests show that even when exposed to moisture stabilizing with Hydrated lime and CG lime increases strength (bearing capacity).

The lime byproduct from the Carbide Graphite facility should be used on a trial basis as a soil subgrade stabilizer. Laboratory testing should be conducted on site-specific soils to determine the appropriate percentage of the CG hydrated lime byproduct to use and to insure that the CG lime reacts properly with the soils of a trial site. Such procedures are used when soils are tested to determine if hydrated lime can be used for stabilization. Long-term swelling tests (21 days, or greater) should be conducted on the site-specific soils to insure that detrimental swelling does not occur. Standard hydrated lime specifications used by the Kentucky Transportation Cabinet should be followed when the CG lime is used in the trial section. A test section could be constructed on a project where hydrated lime is scheduled to be used. It would be desirable to observe the performance of the test section for a selected period of time after construction.

A chemical analysis should be performed to determine the amount of calcium hydroxide available to react with the soils, and to determine if any unsuitable substances are present in the hydrated lime byproduct. Also, moisture content of the hydrated lime byproduct would need to be fairly constant to insure the correct percentage of CG lime byproduct, by dry weight, is applied. Moisture content of the CG hydrated lime byproduct used for testing samples described in this report was about ten percent. Moisture content of the CG hydrated lime byproduct used previously (2) percent. Personnel at the Kentucky Transportation Cabinet, Division of Materials, Geotechnical Branch reported a moisture content of about 30 percent for the CG lime byproduct.

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