



KENTUCKY TRANSPORTATION CENTER

STOCKPILING HYDRATED LIME-SOIL MIXTURES





OUR MISSION

We provide services to the transportation community
through research, technology transfer and education.

We create and participate in partnerships
to promote safe and effective
transportation systems.

OUR VALUES

Teamwork

Listening and communicating along with
courtesy and respect for others.

Honesty and Ethical Behavior

Delivering the highest quality
products and services.

Continuous Improvement

In all that we do.

Stockpiling Hydrated Lime-Soil Mixtures

By

Tommy C. Hopkins
*Program Manager and
Chief Research Engineer*

Tony L. Beckham
Former Research Geologist

Charlie Sun
Research Engineer Sr.

**Kentucky Transportation Center
College of Engineering
University of Kentucky**

**in cooperation with the
Kentucky Transportation Cabinet
The Commonwealth of Kentucky
and
Federal Highway Administration**

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data herein. The contents do not necessarily reflect the official views or policies of the University of Kentucky, Kentucky Transportation Cabinet, nor the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

June 2007

1. Report No. KTC-06-07-12/SPR-313-06-1F		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Stockpiling Hydrated Lime-Soil Mixtures				5. Report Date June 2007	
				6. Performing Organization Code	
				8. Performing Organization Report No. KTC-06-07-12/SPR-313-06-1F	
7. Authors Tommy C. Hopkins, Tony L Beckham, Charlie Sun				10. Work Unit No. (TRIAS)	
9. Performing Organization Name and Address University of Kentucky College of Engineering Kentucky Transportation Center 176 Oliver Raymond Building Lexington, KY 40506-0281				11. Contract or Grant No. KY SPR-06-313	
12. Sponsoring Agency Name and Address Kentucky Transportation Cabinet 200 Mero Street Frankfort, KY 40622				13. Type of Report and Period Covered Final	
				14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the Federal Highway Administration, US Department of Transportation					
16. Abstract The concept and feasibility of stockpiling and reusing hydrated lime-soil mixtures to stabilize particular areas on stabilization projects after the mixing contractor has departed were examined. In chemical stabilization of subgrades, situations often arise where additional areas need to be stabilized after the specialty contractor and mixing equipment have left the project. Field and laboratory investigations were performed to determine if a soil mixed with hydrated lime during routine lime subgrade stabilization could be mixed, stockpiled, and used later. In laboratory studies, hydrated lime-soil mixtures were stockpiled loosely in the laboratory. CBR specimens of the stockpile material were remolded and soaked at selected times. Values of CBR increased with increasing times. Those studies strongly indicated that hydrated soil-mixtures could be stockpile and reused. Field trials were conducted on KY Route 1303 (Turkey Foot Road) in Kenton County, Kentucky. During stabilization of the mainline of that route a stockpile was constructed and cured. Subgrade areas of two intersections could not be stabilized by the specialty contractor because traffic had to be maintained during chemical stabilization of the mainline subgrade. About two or three months after the construction of the stockpiles, pavements at two intersections were removed and the top ten inches of the subgrades were constructed with hydrated lime-soil mixtures from the stockpile. In situ CBR tests were conducted on the treated subgrades of the two intersections after 8 and 28 days, and 20 months and 7 days and 20 months, respectively, after construction. The soaked laboratory CBR value of subgrade soils in this area is about 1.8 at the 85 th percentile test value. At one intersection, the in situ CBR values of the treated subgrade after 7 and 28 days ranged from 7 to 18.3 and 11.7 to 18.1, respectively. Twenty months after construction, the in situ CBR ranged from 9.4 to 21.1. At the other intersection, the in situ value ranged from 4.5 to 10.2. However, 20 months after construction, the insitu CBR value ranged from 14.8 to 24.2. Bearing capacity analyses of the two flexible pavements of the two intersections, using a newly developed bearing capacity model based on limit equilibrium, yielded estimated factors of safety of 1.55 and 2.02, respectively. Factors of safety of this magnitude usually predict excellent long-term performances. After twenty months, pavements resting on the treated subgrades constructed of stockpile hydrated-lime soil have performed very well. It was recommended that other sites containing different types of soils should be evaluated to fully validate the stockpile concept.					
17. Key Words Subgrade Stabilization, Stockpiled Soil-Hydrated Lime				18. Distribution Statement Unlimited, with approval of the Kentucky Transportation Cabinet	
19. Security Classification (of this report) None		20. Security Classification (of this page) None		21. No. of Pages 30	
				22. Price	

TABLE OF CONTENTS

LIST OF FIGURES vii

LIST OF TABLES ix

EXECUTIVE SUMMARY xi

INTRODUCTION1

INITIAL LABORATORY TESTING3

 Red Clay from Hardin County, Kentucky3

 Grayish Brown Clay from Kenton County, Kentucky (KY 1303, Turkey Foot Road)3

CONSTRUCTION PROCEDURES AND FIELD TESTING4

IN SITU TESTING OF ROADWAY AREAS ADJACENT TO THE TWO INTERSECTIONS ..9

FIELD AND LABORATORY STUDIES 20 MONTHS AFTER CONSTRUCTION.....13

 Pavement Thickness at the Intersections13

 In Situ CBR.....13

 Long-Term Laboratory CBR Tests on Hydrated Lime-Soil Stockpile Mixtures.....16

ANALYSIS16

 Comparison of Moisture-Dry Density Relationships16

 In Situ CBR Values.....17

 Comparison of Long-Term Values of Laboratory CBR and In Situ CBR18

 Bearing Capacity Analysis.....19

SUMMARY AND CONCLUSIONS.....21

RECOMMENDATIONS21

ACKNOWLEDGEMENTS23

REFERENCES.....23

APPENDIX25

 SECTION 208 $\frac{3}{4}$ CHEMICALLY STABILIZED ROADBED

LIST OF FIGURES

Figure 1. Site map (from Kentucky Transportation Cabinet Division of Planning Interactive Map Web Site)	1
Figure 2. CBR Values from KY 1303, Kenton County, Sections 1 and 2 (data from Kentucky Transportation Cabinet, Division of Materials, Geotechnical Branch)	2
Figure 3. Percentile test values from laboratory CBR tests sections 1 and 2 (data from Kentucky Transportation Cabinet, Division of Materials, Geotechnical Branch)	2
Figure 4. Results of unconfined compressive strength tests used to determine the feasibility of reusing hydrated lime-soil mixtures	3
Figure 5. Moisture-dry density relationships of untreated and hydrated lime-treated residual soil from KY Route 1303	4
Figure 6. Maximum dry density as a function of optimum moisture content obtained from moisture density tests performed on samples collected along the construction corridor of Ky route 1303.....	4
Figure 7. Removal of existing pavement and subgrade at Woodlyn Hill Drive intersection	6
Figure 8. Compacting stockpiled hydrated lime soil subgrade, Woodlyn Hill Drive.....	6
Figure 9. Addition of water to stockpiled hydrated lime-soil subgrade	7
Figure 10. Mixing stockpile hydrated lime-soil with a front end-loader, Stevenson Road.	8
Figure 11. Pavement coring using high volume air pressure to avoid wetting the chemically treated and untreated subgrade layers	8
Figure 12. Use of phenolphthalein solution to determine the thickness of a hydrated lime stabilized subgrade core sample from the mainline roadway.....	10
Figure 13. Pavement coring using high volume air pressure to avoid wetting the chemically treated and untreated subgrade layers	13
Figure 14. Measuring asphalt pavement thickness from a core.....	14
Figure 15. Determining thickness of hydrated lime treated subgrade using phenolphthalein solution at the Woodlyn intersection	14
Figure 16. Pavement cross sections at the Stevenson and Woodlyn Intersections, KY 1303	14
Figure 17. Performing in situ CBR test on top of the hydrated-lime stockpile layer	14
Figure 18. View of standing water at the top of hydrated lime-soil subgrade (Location 2).....	15

Figure 19. CBR as a function of penetration value and soaking period16

Figure 20. Laboratory values of CBR obtained from remolded specimens of the hydrated lime-soil stockpile material from KY 1303 as a function of soaking time17

Figure 21. Comparison of moisture-dry density curves17

Figure 22. Comparison of CBR values measured on the Stevenson Road treated subgrade and the main roadway treated subgrade.....18

Figure 23. Comparison of CBR values measured on the Woodlyn Drive treated subgrade and the main adjacent roadway treated subgrade18

Figure 24. Comparison of laboratory CBR values of soaked specimens of stockpile hydrated lime-soil mixture to values of in situ CBR and CBR values of the main line hydrated lime-soil subgrade19

Figure 25. Graphical User Interface illustrating the bearing capacity analysis of the Woodlyn Hill Intersection.....19

LIST OF TABLES

Table 1. Laboratory CBR values from composite subgrade sample with and without hydrated lime5

Table 2. Seven-Day In place CBR values adjacent to Woodlyn Hill Drive intersection obtained after conventional subgrade stabilization.....5

Table 3. Seven-day in place CBR values on stockpiled soil-lime; Woodlyn Hill Drive intersection.....7

Table 4. Twenty-eight day in place CBR values on stockpiled soil-lime; Woodlyn Hill drive intersection.....7

Table 5. Eight-Day in place CBR values on stockpiled soil-lime; Stevenson Road intersection...9

Table 6. Results of field and laboratory tests to determine thickness and strength parameters11

Table 7. Results from stability analysis for stabilized subgrade with reduced thickness12

Table 8. In place CBR values on stockpiled soil-hydrated lime; Stevenson Road intersection ...15

Table 9. In place CBR values on stockpiled soil-hydrated lime; Woodlyn Drive intersection15

Table 10. Results of long-term laboratory CBR tests performed on hydrate lime-soil mixtures from the stockpile at KY 1303.....16

Table 11. Results from bearing capacity analysis of the two intersections constructed on the stockpile hydrated lime-soil mixture20

EXECUTIVE SUMMARY

The concept and feasibility of stockpiling and reusing hydrated lime-soil mixtures to stabilize particular areas on stabilization projects after the mixing contractor has departed was examined. In chemical stabilization of subgrades, situations often arise during construction where additional areas need to be stabilized after the specialty contractor and mixing equipment has left the project. Stockpiling material for those locations appeared to be a viable alternative.

Field and laboratory investigations were performed to determine if a soil mixed with hydrated lime during routine lime subgrade stabilization could be mixed, stockpiled, and used later. Field trials were conducted on KY Route 1303, (Turkey Foot Road) in Kenton County Kentucky. Results from field and laboratory tests are presented. Construction procedures are documented.

Hydrated lime-soil mixtures were stockpiled and used to construct subgrades at two intersections after completion of hydrated lime-soil stabilization of the mainline subgrade. The two intersections had to be left open while the majority of the project was stabilized. Approximately two months after construction of the hydrated lime-soil stockpile, the pavement at the Woodlyn Hill Drive intersection was removed and the stockpile was used to construct the top 10 inches of the subgrade. Similarly, at the Stevenson Road intersection, the pavement was removed and the top 10 inches of the subgrade was constructed using stockpiled hydrated lime-soil mixture. In situ CBR values from tests conducted about 8 days, 28 days, and 20 months after construction of the stockpiled subgrades, ranged from 8.3 to 18.2, 13.3 to 18.2, respectively, for the Woodlyn Hill Drive site. Seven days after construction, in situ CBR values of the stockpile subgrade at the Stevenson Road intersection ranged from 4.5 to 10.3. Subgrade rutting occurred when the contractor prematurely started hauling and placing aggregate on the finished subgrade. The surface was rerolled and sufficient time was allowed for the subgrade to cure before placement of the pavement. About 20 months after construction, in situ CBR values ranged from 14.8 to 24.2.

Although the in situ CBR values of the stockpile subgrades of the two intersections were slightly smaller than in situ values of the mainline stabilized subgrades, the subgrades strengths were more than adequate to provide good stability for the flexible pavements. In situ CBR values measured after 20 months were about 5 to 13 times greater than the soaked, laboratory CBR (1.8 at the 85th percentile test value) of the untreated soils in this area. Bearing capacity analyses of the two intersections showed that the factors of safety ranged from 1.55 to 2.02. Based on past observations and analysis, values of this magnitude usually predict that flexible pavements will have good long-term performances. The use of stockpile hydrated lime-soil mixture was successfully used at the two intersections.

Based on the findings and conclusions of this study, the following recommendations are made:

- Further long-term monitoring, observations, and in situ testing of the Woodlyn Hill and Stevenson Road (Turkey Foot Road, Ky Route 1303) intersections are needed to establish the long-term performances of the flexible pavements and the subgrades constructed with stockpiled soil-hydrated lime mixtures.
- Additional sites should be evaluated. It is strongly recommended that another site in the Kope shale area, as well as other sites involving different types of soils, such as the red

clays of the Mississippian Plateau and the Bluegrass Physiographical Regions of Kentucky, should be selected for evaluation of the hydrated lime-soil stockpile concept.

Create a special note, or provision, for stockpiled hydrated-lime mixtures and make the note available to insert into future highway projects, or future pilot projects. Standard Specifications, Edition 2004, pertaining to chemical stabilization of soil subgrades (using lime) should be followed as closely as practical (see Appendix).

INTRODUCTION

Reconstruction of existing KY Route 1303 (Section 2), in Kenton County included one intersection where traffic needed to be maintained and another intersection where traffic could be detoured for only few days. The section of roadway lies between two others that were previously constructed with hydrated lime-stabilized subgrades. A location map is shown in Figure 1. Hydrated lime stabilization was not recommended for this section because of construction scheduling concerns around the intersections. Construction engineers in Highway

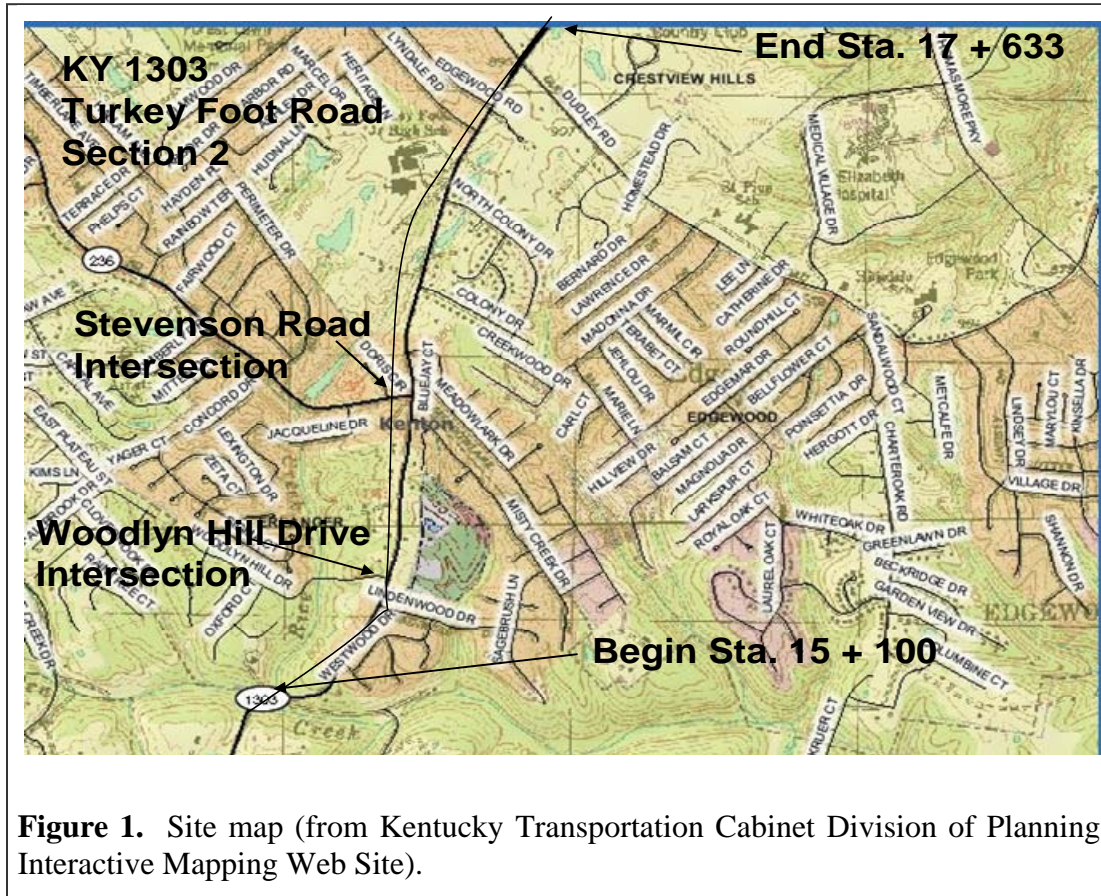


Figure 1. Site map (from Kentucky Transportation Cabinet Division of Planning Interactive Mapping Web Site).

District Six of the Kentucky Transportation Cabinet wanted to construct hydrated lime-subgrade stabilization so that a uniform subgrade existed throughout the entire length of the roadway. The two intersections were left open to traffic during most of the construction. Woodlyn Hill Drive was closed for a few days when the intersection that contained the mainline was constructed.

Stevenson Road (KY Route 236) was left open to traffic at all times. A new intersection was constructed while traffic was maintained on the old one. When traffic was rerouted to the new intersection the portion of pavement that was in the mainline route was removed and a hydrated lime-stabilized subgrade was constructed with stockpiled material. The route was opened to traffic in October 2005.

Hydrated lime and other types of chemical stabilization have been used to improve the bearing capacity of highway subgrades for many years (Hopkins et al, 1986, 1987, 1988, 1994,

and 2002; Hopkins 1991). The roadway was constructed through the Kope Geological Formation, which contains mostly shale with some interbedded limestone layers. The shale and the residual soils have very poor engineering properties.

Two separate geotechnical reports were prepared for Sections 1 and 2 by the Geotechnical Branch (1998), Division of Materials, Kentucky Transportation Cabinet.

Hydrated lime subgrade stabilization was recommended for Section 1, the adjacent section situated south of Section 2, because of the low values of CBR (soaked) associated with the soils. Hydrated lime stabilization was not recommended for Section 2 because of construction concerns, even though the CBR values for the section were very low and stabilization would normally be recommended.

Thirteen of fourteen CBR samples that were tested had CBR values of 7 percent or less in Section 1. Thirteen of fifteen CBR samples had CBR values of 7 percent or less for Section 2. Past research (Hopkins, et al 1994) has recommended using chemical stabilization to improve CBR strength when the CBR value is less than about 7 percent. Results from laboratory CBR tests

performed during the initial geotechnical investigation (Molen, 1998) are shown in Figure 2. The percentile test value as a function of CBR laboratory tests is shown in Figure 3. At the 85th percentile test value the CBR value is 3.1 for Section 1, 2.6 for Section 2, and 2.8 for the two sections combined. Normally the 85th percentile test value is an acceptable selection for pavement design (Hopkins 1991). The use of chemical stabilization (hydrated lime) was fully justified in this case.

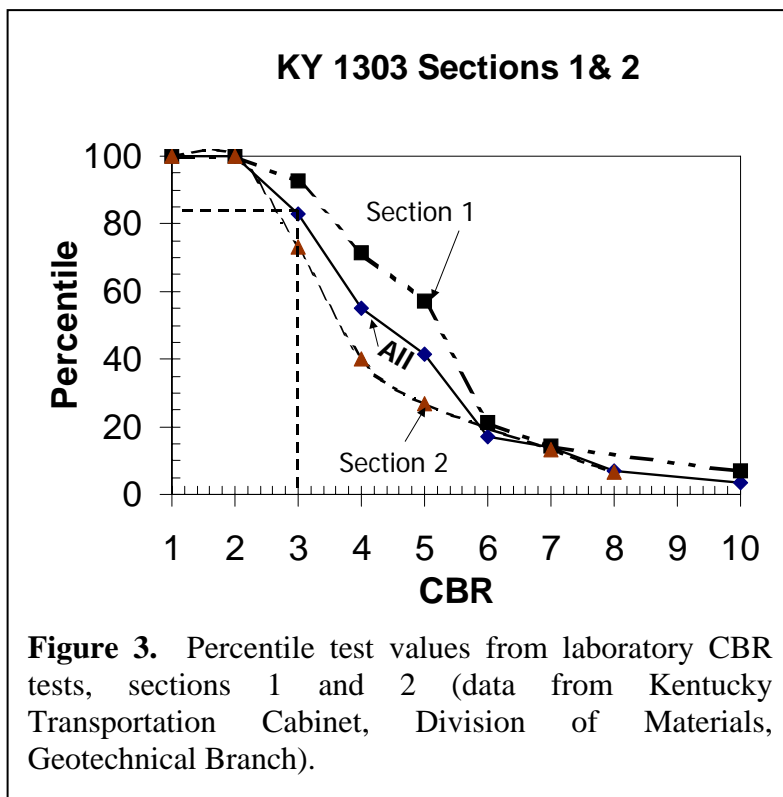


Figure 3. Percentile test values from laboratory CBR tests, sections 1 and 2 (data from Kentucky Transportation Cabinet, Division of Materials, Geotechnical Branch).

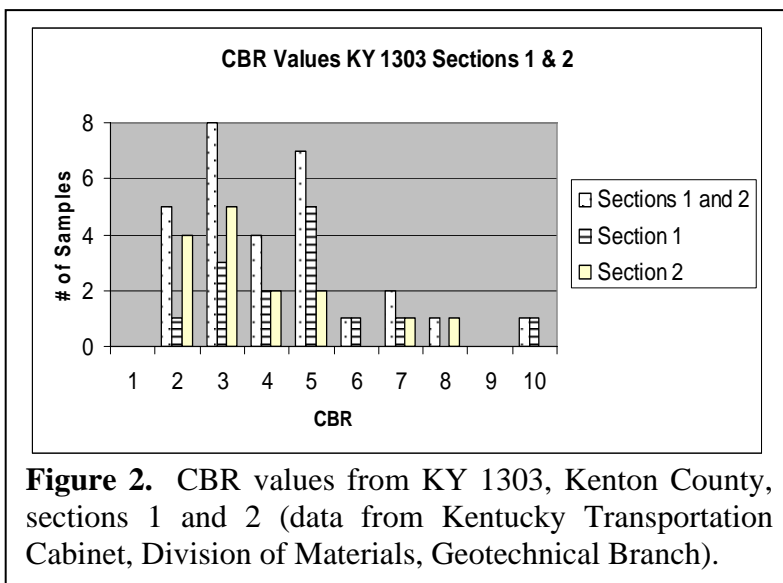


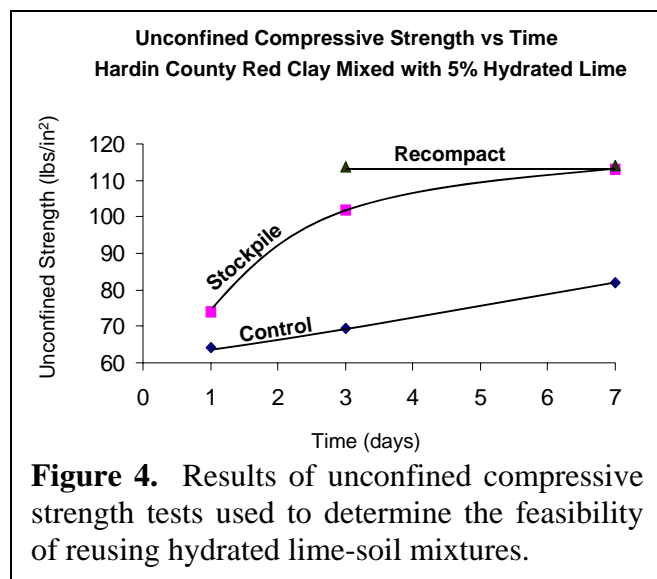
Figure 2. CBR values from KY 1303, Kenton County, sections 1 and 2 (data from Kentucky Transportation Cabinet, Division of Materials, Geotechnical Branch).

INITIAL LABORATORY TESTING

A series of unconfined compressive strength tests were performed on one of six bulk soil samples the Kentucky Transportation Center, Geotechnology Section, keeps for reference testing and a clay soil from a construction site in Northern Kentucky. Classification and moisture-density tests were performed previously on the reference soils. The tests were performed to determine the feasibility of using stockpiled hydrated lime-soil and reusing it later.

Red Clay from Hardin County, Kentucky

The sample used in the first trial was red clay collected from Hardin County, Kentucky. The reference soil was classified as CH and A-7-6 by the Unified and AASHTO Classification Systems, respectively. These types of clays, which are derived from limestone bedrock in central and south central Kentucky, have reacted very well in the past when used for highway subgrade lime stabilization. A large sample of the red clay was mixed with five percent (by dry mass) of hydrated lime, covered to prevent moisture loss, and mellowed for one hour. Three samples of the lime-clay mixture were compacted at optimum moisture content and 95 percent of maximum dry density for future unconfined compressive strength tests at one, three and seven days of curing. The samples were sealed after compaction to prevent moisture loss and curing was at room temperature. These samples are identified as “Control” samples in Figure 4. Unconfined compressive strengths were about 65, 70, and 82 psi respectively for 1, 3, and 7 days of curing time. The remaining soil-lime mixture was loosely covered with plastic.



After twelve days, three additional samples were compacted for testing at the same time intervals (1, 3, and 7 days) under the same conditions. Some water was added at the time of compaction to reach optimum moisture content. Unconfined strengths were about 82, 102, and 114 psi for the respective curing times. These strengths were greater than the strengths of the control samples. Test results, which are identified as “Stockpile” samples, are shown in Figure 4. Two additional specimens were recompacted from the control samples tested at three and seven days curing time. The samples, identified

as “Recompact” in Figure 4, were recompacted and cured for three and seven day before testing. Unconfined strengths for these two specimens were about 114 psi, which is equal to the seven-day strength of the stockpile specimens. Preliminary laboratory test results indicated that the reuse of soil-hydrated lime mixtures after stockpiling is feasible.

Grayish Brown Clay from Kenton County, Kentucky (KY 1303, Turkey Foot Road)

Two bulk subgrade samples were obtained from the Turkey Foot Road subgrade at each end of the project near Stations 16 + 040 and 17 + 220. The subgrade was constructed near the proper

grade. The samples were returned to the laboratory, and combined into one composite sample. Classification tests were performed after combining the two samples. The sample was classified as a CH, or a fat clay, and A-7-6 with a Group Index of 28 by the Unified and AASHTO Classification Systems, respectively. About 51 percent of the particles were finer than the 0.002-mm diameter. Hydrated lime stabilization is very effective in improving the engineering properties of this type of soil. According to the Geotechnical Engineering Roadway Report (Kentucky Transportation Cabinet, Geotechnical Branch 1998) for this project, the soils along the construction corridor were classified mainly as CL and CH and A-6 (11 to 15) and A-7-6 (16 to 36), respectively.

Compaction tests to establish moisture-density relations were performed on the composite sample (Figure 5) and the sample mixed with five percent (by dry mass) of hydrated lime. Based on data from numerous tests and contained in the Geotechnical Engineering Roadway report, the relationship between maximum dry density and optimum moisture content of the soils along the construction corridor of Ky 1303 is shown in Figure 6. Compaction test results obtained for the composite sample are compared to the relationship.

Moisture–density tests are required to yield the required compaction parameters for laboratory CBR tests. Laboratory CBR tests were performed on the sample with no hydrated lime added and on samples with five percent hydrated lime added. Testing procedures used were those specified by the Kentucky Transportation Cabinet except additional moisture content information was obtained. The non-stabilized sample was soil only. The stockpile sample identified as zero days was compacted one hour after the soil-hydrated lime mixing was completed and soaked in water for the specified time. The 7-day stockpile sample was compacted after the soil-hydrated lime mixture had sit for seven days loosely covered. Moisture was added during compaction to reach the desired optimum moisture content. The 44-day stockpile CBR test was performed the same way except the material rested for 44 days. As shown in Table 1, the addition of hydrated lime vastly improved the laboratory CBR values. Allowing the material to sit loosely for several days in a stockpile did not change CBR values significantly.

CONSTRUCTION PROCEDURES AND FIELD TESTING

Subgrade stabilization began in June 2005 at the north end of the section and proceeded south to about 100 feet north of Stevenson Road, which remained open to traffic.

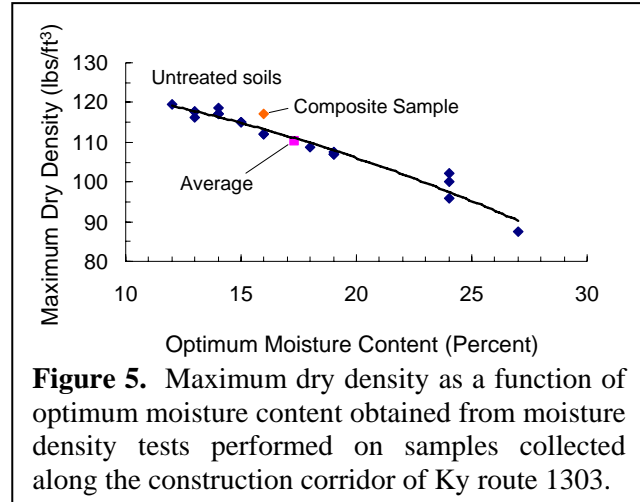


Figure 5. Maximum dry density as a function of optimum moisture content obtained from moisture density tests performed on samples collected along the construction corridor of Ky route 1303.

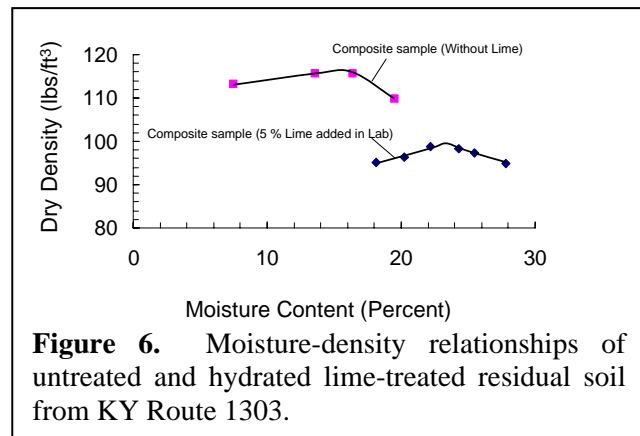


Figure 6. Moisture-density relationships of untreated and hydrated lime-treated residual soil from KY Route 1303.

The in situ lime-soil stockpile was constructed on June 23 by mixing hydrated lime with soil using the same techniques used in subgrade stabilization except no compaction criteria was required. The lime slurry was applied to scarified soil on an area on the right of way, but outside of the newly constructed roadway. The hydrated lime was mixed into the soil and lightly compacted. Secondary mixing, compaction, and sealing with an asphalt membrane were

Table 1. Laboratory CBR values from composite subgrade sample with and without hydrated lime.

Sample	CBR at Penetration							
	Moisture Content (%)			0.1 inch	0.2 inch	0.3 inch	0.4 inch	0.5 inch
	Initial	Final	Top Inch					
Non-stabilized	25.0	28.5	35.0	1.4	1.4	1.4	1.3	1.3
0 Day stockpile	23.2	22.3	25.6	51.6	37.2	31.6	26.7	26.0
7 Days stockpile	23.6	25.0	26.6	44.7	28.9	24.7	22.6	22.0
44 Days stockpile	24.2	24.5	24.6	42.1	28.3	24.0	21.8	20.3

performed the next day. The lime-soil mixture remained in place until it was excavated for reuse. Additional soil-lime material was obtained when final grade was cut on the lime-stabilized subgrade and stockpiled on site.

Subgrade stabilization then was moved to the south end of the project and it proceeded north toward Stevenson Road. Stabilization of the subgrade stopped near Station 15 + 390, south of Woodlyn Hill Drive, and resumed about Station 15 + 429, north of the intersection. Woodlyn Hill Drive remained open to traffic with the original pavement intact. A new intersection for Stevenson Road was constructed south of the existing intersection. Traffic was maintained on the existing intersection during construction of the new intersection. In place CBR tests were

Table 2. Seven-Day In place CBR values adjacent to Woodlyn Hill Drive intersection obtained after conventional subgrade stabilization.

Test ID	CBR at Penetration					
	Moisture Content (%)	0.1 inch	0.2 inch	0.3 inch	0.4 inch	0.5 inch
South End	19.8	25.6	24.0	22.0	Not Tested	Not Tested
South End	18.8	20.7	19.9	18.6	17.8	17.1
North End	26.5	12.1	15.3	15.8	15.3	15.5

performed at three locations near the intersection after seven days of curing time. Results from those tests are shown in Table 2. The lowest value measured was 12.1 percent and the largest was 25.6 percent. Although not as large as laboratory CBR values for lime stabilized soil, the values were adequate to support construction traffic.

Woodlyn Hill Drive was closed to traffic on August 22, 2005 and the intact pavement and aggregate base were removed to the desired elevation, as shown in Figure 7. Excavation was completed on August 23 and the lime-soil subgrade was constructed on the same day. Dense graded aggregate was placed on the subgrade the next day. Typically, a seven-day curing time is required for lime- subgrade stabilization. The stabilized subgrade was constructed by placing



Figure 7. Removal of Existing Pavement and Subgrade at Woodlyn Hill Drive Intersection

material from the stockpile of cuttings. The lime-stabilized subgrade was constructed in two lifts. Approximately, 5-6 inches of lime-soil was removed from the in situ stockpile and placed on the existing subgrade. The in situ stockpile was constructed 61 days earlier. The mixture was spread with a self-propelled static sheepsfoot roller (Figure 8). Water was added through a distributor attached to a truck mounted water tank as shown in Figure 9. Water was added until it appeared that the soil-hydrated lime mixture was about two percent over optimum moisture content.

The mixture was then compacted with a static sheepsfoot roller. A second lift was then constructed using this procedure.

In place CBR tests were performed at two locations seven days after the subgrade was constructed.



Figure 8. Compacting stockpiled hydrated lime soil subgrade, Woodlyn Hill Drive.

The dense graded aggregate base, asphalt drainage blanket, and all asphalt concrete layers except the asphalt surface were constructed prior to in place CBR testing. CBR values from the seven-day tests ranged from 7.0 to 14.3 percent and are shown in Table 3. Again, these values were smaller than laboratory values.

Additional in place CBR tests were performed at the Woodlyn Hill Drive Intersection twenty-eight days after the subgrade was constructed. The tests were performed near the locations that had been tested after

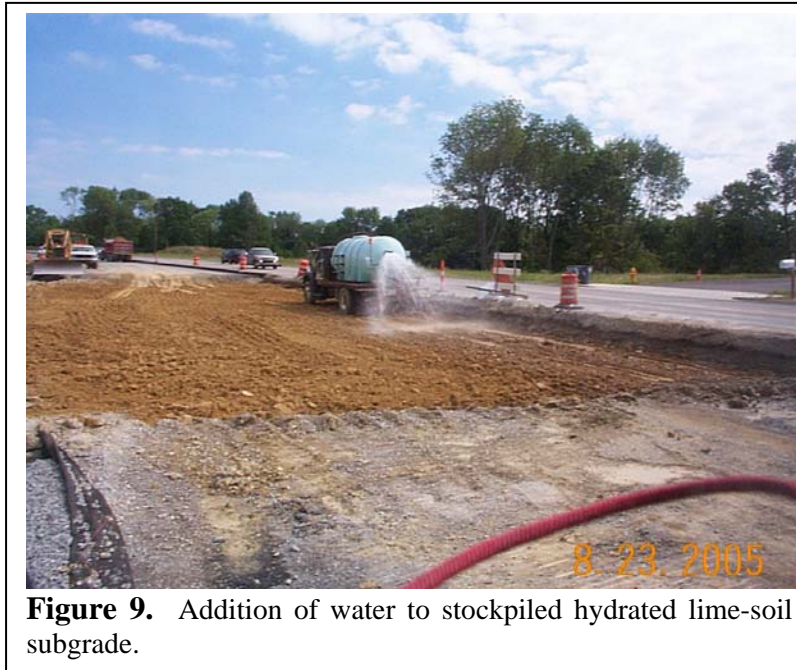


Figure 9. Addition of water to stockpiled hydrated lime-soil subgrade.

seven days. In place CBR values increased on the south end of the intersection and were slightly smaller than values measured on the north end. Overall the values should be adequate to support traffic. Results from the 28-day tests are shown in Table 4.

The existing pavement and subgrade at Stevenson Road-KY 1303 was removed to the planned elevation on October 3. The Stevenson Road intersection had been permanently moved south of the existing location and traffic was rerouted to it.

A soil-hydrated lime mixture

Table 3. Seven-day in place CBR values on stockpiled soil-lime; Woodlyn Hill Drive intersection.

Test ID	Moisture Content (%)	CBR at Penetration				
		0.1 inch	0.2 inch	0.3 inch	0.4 inch	0.5 inch
South End	31.4	7.0	8.3	8.8	8.7	8.9
North End	38.0*	18.3	18.2	16.8	15.2	14.3

*Free water was present during testing.

obtained from a loose stockpile was used at the subgrade of the Stevenson Road Intersection. This stockpile was located just north of the Stevenson Road intersection. The stockpile of soil-hydrated lime material was created from cuttings that were removed from the lime-stabilized subgrade located north of Stevenson Road in June 2005 because the grade had been constructed too high. Instead of wasting the material it was suggested that the material be stockpiled and used to create a stabilized subgrade at this intersection.

Table 4. Twenty-eight day in place CBR values on stockpiled soil-lime; Woodlyn Hill drive intersection.

Test ID	Moisture Content (%)	CBR at Penetration				
		0.1 inch	0.2 inch	0.3 inch	0.4 inch	0.5 inch
South End	32.4	16.3	18.1	17.5	16.6	16.1
North End	28.7	11.7	13.3	13.8	13.2	12.3

The hydrated lime-soil mixture was placed at the intersection approximately between stations 16 + 096 and 16 + 135. The location of the end of the hydrated lime-stabilized soil subgrade south of Stevenson Road was reported to be at Sta. 16 + 105. No soil-lime subgrade was observed at that station. The pavement (asphalt drainage blanket and DGA) layers were removed to Sta. 16 + 096 where some soil-lime subgrade was observed at the sides but not in the center. Two base courses had been constructed over the drainage blanket and DGA to this point.

The decision was made by the resident engineer not to remove the asphalt base courses and curb. One four-inch layer of the stockpiled soil-lime was placed in an approximately 5 inch-loose lift. The water and soil-lime subgrade were mixed with the teeth of a front-end loader (Figure 10). Water was added using a hand-held hose attached to a truck-mounted water tank instead of using a distributor bar attached to a water truck, which was used previously. Water was added until two moisture content readings showed 26 and 27 percent, respectively on a nuclear moisture-density gage. Optimum moisture content was believed to be around 22-24 percent. Optimum was not known exactly because the material from the stockpile was from cuttings obtained on the entire northern end of the project. The water and soil-lime subgrade were mixed with the teeth of a front-end loader. The lift was lightly compacted with a vibratory sheepsfoot roller as opposed to a static sheepsfoot roller used at the Woodlyn Hill Drive intersection. A second 5-inch loose lift was placed and water added



Figure 10. Mixing stockpile hydrated lime-soil with a front end-loader, Stevenson Road.

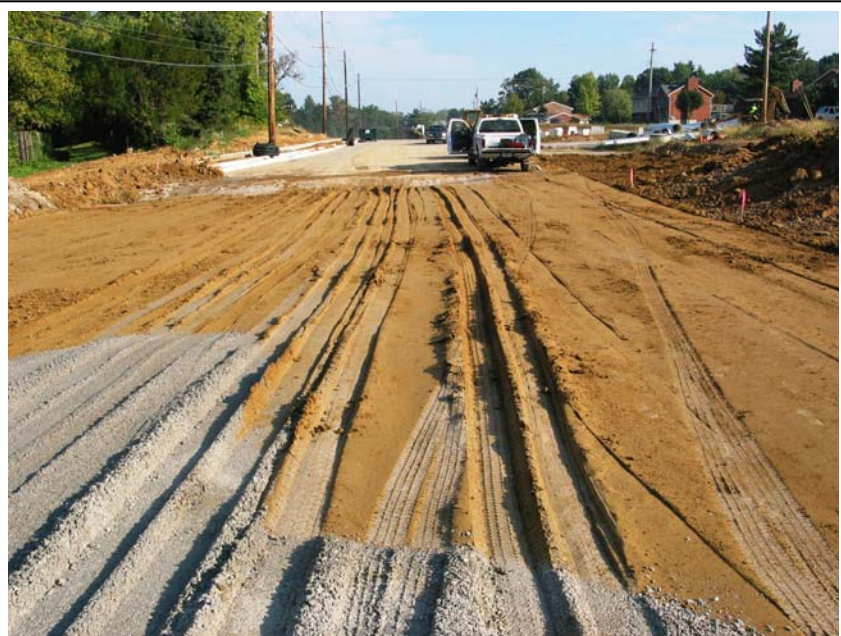


Figure 11. Subgrade rutting from construction traffic, Stevenson Road.

A second 5-inch loose lift was placed and water added

until the moisture content was measured at 26 percent. Mixing was performed with the loader bucket. Final compaction was done with a vibratory sheepsfoot roller.

The lime-stabilized subgrade at Stevenson Road intersection was compacted with a smooth-wheel vibratory roller the next day (Oct. 4). Moisture and density were measured and approved. Three truckloads of DGA were placed on the lime-stabilized subgrade (south end) and spread with a small bulldozer in about 5-to 6-inch loose lifts. As shown in Figure 11, the contractor was hauling excess soil south of the new Stevenson Road interchange across the new subgrade in a tandem dump truck and caused severe rutting in the subgrade and loose DGA. The inspector had them quit and reroll the subgrade with a smooth wheel roller. The remaining DGA was placed

Table 5. Eight-day in place CBR values on stockpiled soil-lime; Stevenson Road intersection.

Test ID	CBR at Penetration					
	Moisture Content (%)	0.1 inch	0.2 inch	0.3 inch	0.4 inch	0.5 inch
South End	30.1*	4.5	4.9	5.2	4.7	4.5
North End	24.5	9.1	10.2	10.3	9.8	9.7

* Free water seeping onto subgrade from DGA during test.

with trucks moving over the DGA layer and not the subgrade. No asphalt seal coat was placed on the subgrade.

Two in place CBR tests were performed on the Stevenson Road intersection subgrade constructed with stockpiled hydrated lime-soil material eight days after final construction. The values ranged from about 4.5 to 10.3 percent as shown in Table 5, and were smaller than the seven-day values obtained at Woodlyn Hill Drive intersection previously.

The field CBR values were smaller than those obtained at the Woodlyn Hill Drive intersection but still much greater than the 85th percentile values of untreated soaked compacted soil specimens reported in the initial geotechnical investigation.

IN SITU TESTING OF ROADWAY AREAS ADJACENT TO THE TWO INTERSECTIONS

As a means of comparing bearing strengths of the soil-hydrated lime stockpile subgrades of the Stevenson and Woodlyn intersections to the bearing strengths of subgrades stabilized conventionally with hydrated lime during construction, an in situ testing program was conducted. In addition to providing data for comparisons, the study was also performed for another reason. After the hydrated lime stabilized soil subgrade was constructed from the north end of the section to the Stevenson Road intersection, it was discovered that the final grade was higher than specified and the depth of stabilization exceeded the specified depth of 8 inches (200 mm). Construction personnel requested the Kentucky Transportation Center perform additional testing (field and laboratory) and an engineering stability evaluation. They were concerned that the excess depth of stabilization, which effectively reduced the specified amount of hydrated lime (six percent by dry mass), would create a situation where the subgrade would not provide

adequate strength. They were also concerned that the reduced stabilized subgrade thickness, after cutting to final grade, would not be adequate to support the pavement. The final grade had to be within design tolerances due to the curb and gutter alignment and several business and residential entrances.

In situ CBR tests and the depth of stabilized subgrade was determined from standard penetration tests or from cores obtained for unconfined compressive strength testing. Thickness of the lime-stabilized subgrade was determined by applying phenolphthalein solution to standard penetration test samples immediately after they were obtained. Phenolphthalein is a clear liquid indicator that turns red or pink (See Figure 12) in a high pH environment, which is the case for hydrated lime-stabilized subgrades. Results from field measurements and unconfined compressive strength tests are shown in Table 6.

The pavement was analyzed for stability using a model developed at the Kentucky Transportation Center (Hopkins 1991, 2005). The in place CBR values ranged from about 12 to 46 which are very good from a design point of view. Any value of CBR equal to or greater than 10 is very good. The unconfined compressive strength ranged from about 33 to 64 psi (4,752 to 9,288 lbs/ft²). These values are reasonably good considering it was difficult to get high quality specimens because of rock particles present in the matrix. However, the fact that core samples were obtained from the lime-stabilized layer indicates that the subgrade has reasonable in situ strength.

In a previous study, our analysis shows that for seven-day strengths of hydrated lime-soil



Figure 12. Use of phenolphthalein solution to determine the thickness of a hydrated lime stabilized subgrade core sample from the mainline roadway.

samples the unconfined compressive strength at the 85th percentile test value is about 48 psi. In this case, the value at the 85th percentile test value is about 35 psi. However, the fact that the in situ CBR values ranged from 12 to 46 indicates that the subgrade has reasonably good strength.

The stability model analyses were performed using various assumptions pertaining to the subgrade and other pavement layers. The analyses are summarized in the Table 7. Conservative assumptions were made in performing the analyses. Using the 85th percentile test value of unconfined compressive strength for the treated layer and a very low value of the subgrade (equivalent to a soaked CBR value of 2.0), and assuming a 6-inch layer of treated subgrade, the factor of safety against failure is about 1.24. If the highest value of unconfined strength is used, (and the 6-inch treated layer), then the factor of safety of 1.38 is obtained. If a 10-inch treated layer is used, then the factor of safety of about 1.35 to 1.59 is obtained for strengths ranging from about 35 to 60 psi. However, it interesting to note that if no stabilization had been used, the factor of safety of the pavement section is only 1.10--essentially a failure condition. Considering the conservative nature of the assumptions made in the analyses and the fact that the hydrated lime-soil layer will increase in strength with time, and based on our model analysis, the treated layer has sufficient strength and should perform okay in the future after the pavement is placed.

Table 6. Results of field and laboratory tests to determine thickness and strength parameters.

Location Approximate Station	Measured Stabilized Thickness (inches)	CBR					CBR Moisture Content (%)	Unconfined Compressive Strength (psi)	UCS Moisture Content (%)
		0.1	0.2	0.3	0.4	0.5			
15 + 380	9.5*	25.6	24.0	22.0			19.8	35.8	19.9
15 + 440	9.0*	12.1	15.3	15.8	15.3	15.5	26.5	50.7	18.4
16 + 070	9.0*	20.7	19.9	18.6	17.8	17.1	18.8	64.5	28.3
16 + 160	9.0*	21.3	28.0	29.2			21.1	33.4	22.8
16 + 280	8.0**	46.0	19.8	20.5	19.2	18.7	26.5		
16 + 360	8.0**	39.7	36.0	34.9			21.5		
16 + 480	8.0**	19.7	18.3	17.5	16.6	16.2	20.9	48.3	23.9
16 + 580 ⁺		22.7	22.4	20.4	18.6	17.4	22.4		
16 + 580	6.5**	11.8	14.2	13.8	12.9	12.1	19.6		
16 + 770	6.0**	12.6	12.5	11.9	11.4	10.9	19.6		

* Denotes areas tested as part of a research study for reusing stockpiled hydrated lime stabilized soil.

** Denotes tested areas requested by KYTC Construction personnel. Approximately one inch of lime stabilized soil was removed the day of testing with a grader. The material was removed to allow tests to be performed on material with representative moisture contents. These areas were tested on July 5, 2005. The asphalt curing seal was removed on July 1, 2005 when the grade was being cut causing drying of the surface.

⁺A rock about 5 inches diameter was removed from test area when a moisture content sample was obtained. Moisture Content does not include the rock. A second test was performed in an area with fewer visible rocks.

Table 7. Results from stability analysis for stabilized subgrade with reduced thickness

Asphalt Thickness (inches)	Asphalt Drainage Layer Thickness (inches)	DGA Thickness (inches)	Hydrated Lime-Soil Stabilized Layer Thickness (inches)	Asphalt Strength (assumed from previous test data)		Asphalt Drainage Layer Strength (assumed)		Assumed Strength of Hydrated Lime-Soil Stabilized Layer	Assumed Strength of Untreated Subgrade	⁶ Factor of Safety
				ϕ (deg.)	C (psf)	ϕ (deg.)	C (psf)			
11.5	4	4	6 ¹	43	varied	43	0	2520 ²	617 ⁴	1.24
11.5	4	4	6	43	varied	43	0	4320 ³	617 ⁴	1.38
11.5	4	4	10 ¹	43	varied	43	0	2520 ²	617 ⁴	1.35
11.5	4	4	10	43	varied	43	0	4320 ³	617 ⁴	1.59
11.5	4	4	<i>No stabilized layer</i>	43	varied	43	0	None	617 ⁴	1.10

1. Hydrated Lime stabilized layer ranged in thickness from 6-10 inches (measured).
2. Unconfined compressive strength = 5,040 psf (lowest value obtained from field specimens).
3. Unconfined compressive strength = 8,640 psf (highest value obtained from field specimens).
4. Unconfined strength of about 1,234 psf (8.6 psi) and corresponds to a CBR value of about 2; this value is commonly observed in District 6.
5. Undrained shear strength = 0.5 unconfined compressive strength.
6. Dual wheels and a tire contact stress of 80 psi assumed in the analyses.

FIELD AND LABORATORY STUDIES 20 MONTHS AFTER CONSTRUCTION

During the last week of March 2007, or about twenty months after the Stevenson and Woodlyn intersections were constructed using the stockpile soil-hydrated lime mixture, field and laboratory investigations were conducted. At each intersection, two locations were cored, as shown in Figure 13 to determine the thicknesses of asphalt pavement and Dense Graded Aggregate. Coring was performed using high volume air pressure to avoid wetting the subgrade layers. Split spoon tests were conducted at each site to determine the thickness of the layer constructed below the DGA layer. Two In situ CBR tests were conducted at each intersection on the tops of the stockpile hydrated lime treated layers. Thin-walled tube samples were obtained of both the treated and untreated subgrades at each intersection. Laboratory tests were performed on the collected samples and included grain size, specific gravity, liquid, and plastic limits, and unconfined compression tests.

Pavement Thickness at the Intersections

Thicknesses of the asphalt layers asphalt cores of the pavement at each intersection were determined from measurements, as illustrated in Figure 14. Thickness of layer of hydrated lime stockpile material was determined using phenolphthalein. As illustrated in Figure 15, phenolphthalein reacts with hydrated lime and turns red. Cross sections of the pavement at the two intersections are shown in Figure 16. The pavement at the Stevenson intersection consists of 20 inches of asphalt, 5 inches of DGA, and 10 inches of hydrated lime-treated stockpile material. Dimensions of the Woodlyn intersection are essentially the same except the asphalt layer was about one inch less in thickness than the asphalt layer of the Stevenson Road intersection



Figure 13. Pavement coring using high volume air pressure to avoid wetting the chemically treated and untreated subgrade layers.

In Situ CBR

Two insitu CBR tests were performed on top of the treated subgrade at each intersection. A view of the performance of this test is shown in Figure 17. Minimum values of in situ CBR at the

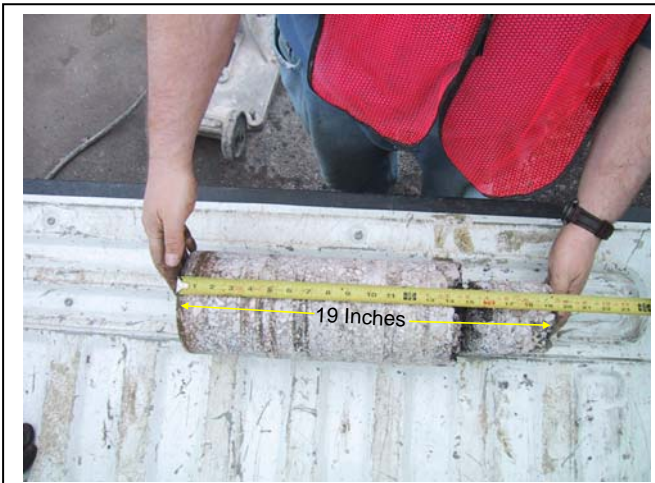


Figure 14. Measuring asphalt pavement thickness from a core.

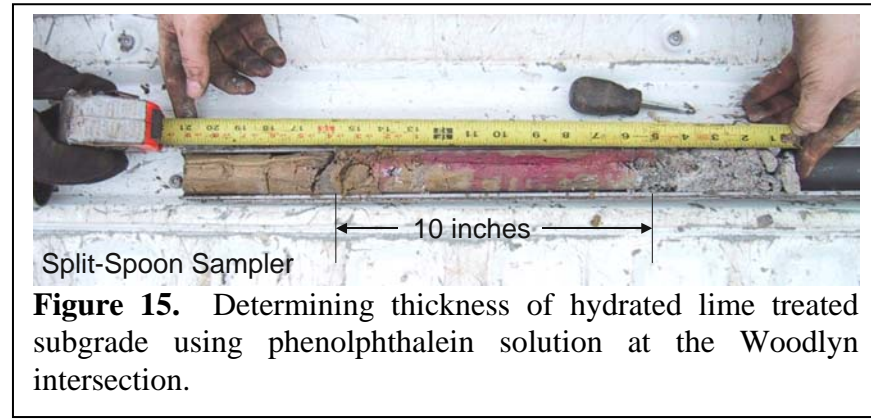


Figure 15. Determining thickness of hydrated lime treated subgrade using phenolphthalein solution at the Woodlyn intersection.

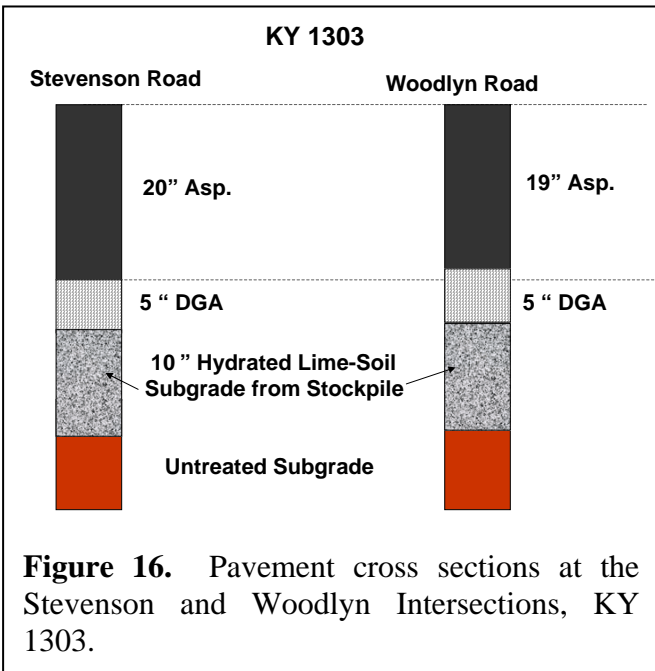


Figure 16. Pavement cross sections at the Stevenson and Woodlyn Intersections, KY 1303.



Figure 17. Performing in situ CBR test on top of the hydrated lime stockpile layer.

At the stockpile subgrade of the Stevenson Road intersection, Table 6, CBR values at 0.1-inch penetration were 14.8 and 18.6. However, the CBR values ranged upward to 25.1 and 27.1 at 0.5 inches of penetration. Although water (Figure 18) was seeping into the hole from the DGA, the standing water at the top of the treated layer apparently had little effect on the CBR value measured at this location.

As shown in Table 7, minimum CBR values occurring at the 0.1-inch penetration at two test locations of the Woodlyn Drive intersection were 9.4 and 21.1. Maximum CBR values at location 1 reanged upward to 12.9 at the 0.5-inch penetration.

At location 2, the minimum value at 0.1-inch penetration was 21.1 and decreased to 14.6 at the 0.5-inch penetration.

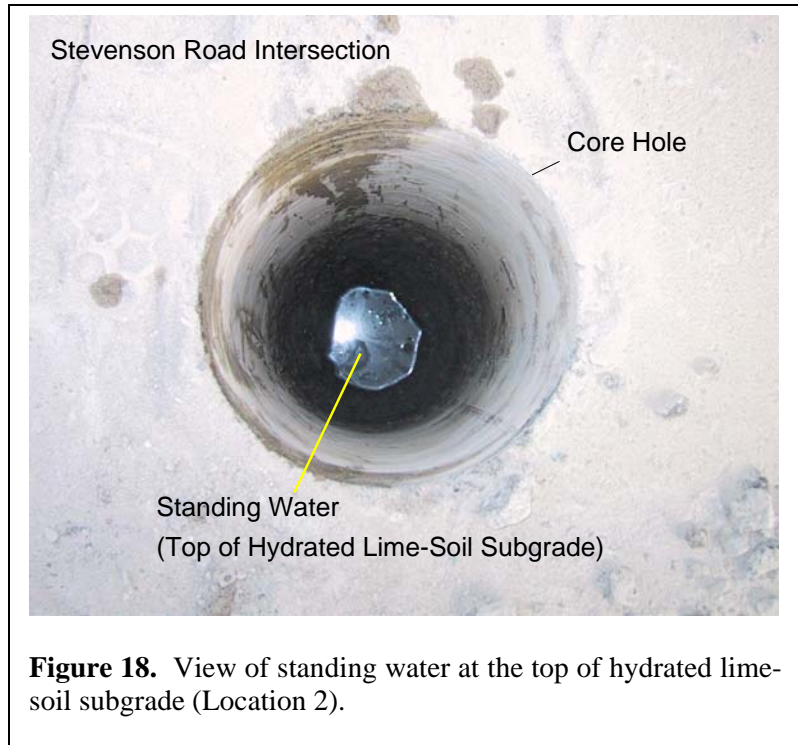


Figure 18. View of standing water at the top of hydrated lime-soil subgrade (Location 2).



Table 8. In place CBR values on stockpiled soil-hydrated lime; Stevenson Road Intersection.

Test ID	Moisture Content (%)	CBR at Penetration				
		0.1 inch	0.2 inch	0.3 inch	0.4 inch	0.5 inch
Location 1	21.1	14.8	19.1	21.8	23.4	25.1
*Location 2	21.6	18.6	24.2	27.3	27.2	27.1

* Free water seeping onto subgrade from DGA during test –See Figure 15.

Table 9. In place CBR values on stockpiled soil-hydrated lime; Woodlyn Drive Intersection.

Test ID	Moisture Content (%)	CBR at Penetration				
		0.1 inch	0.2 inch	0.3 inch	0.4 inch	0.5 inch
*Location 1	29.7	9.4	10.9	12.6	12.4	12.9
Location 2	39.2	21.1	18.6	17.3	15.4	14.6

* Free water seeping onto subgrade from DGA during test.

Table 10. Results of long-term laboratory CBR tests performed on hydrate lime-soil mixtures from the stockpile at KY 1303.

Specimen Number	Date Stockpile Created	Test Dates	Elapsed Time Before Soaking (days)	Soaking Period (days)	Moisture Content After Test (%)	CBR at Penetration				
						0.1 inch	0.2 inch	0.3 inch	0.4 inch	0.5 inch
SP0	6/24/2005	1/20/2006	210	0		48.2	39.4	32.7	27.6	25.7
SP1		1/26/2006	216	1		35.9	25.4	21.9	20.3	19.6
SP2		1/27/2006	217	2		36.6	27.8	23.8	21.7	21.2
SP5		2/1/2006	222	5		38.4	30.3	27	25	--
SP7		1/27/2006	217	7		31.6	29.1	25.5	23.5	22.2
SP30					30					
Sp130		10/24/2006	487	130		134	81.7	69.7	64.2	63.3

Lime stabilized stockpile created 6/24/06. Lab sample taken at that date for above tests.

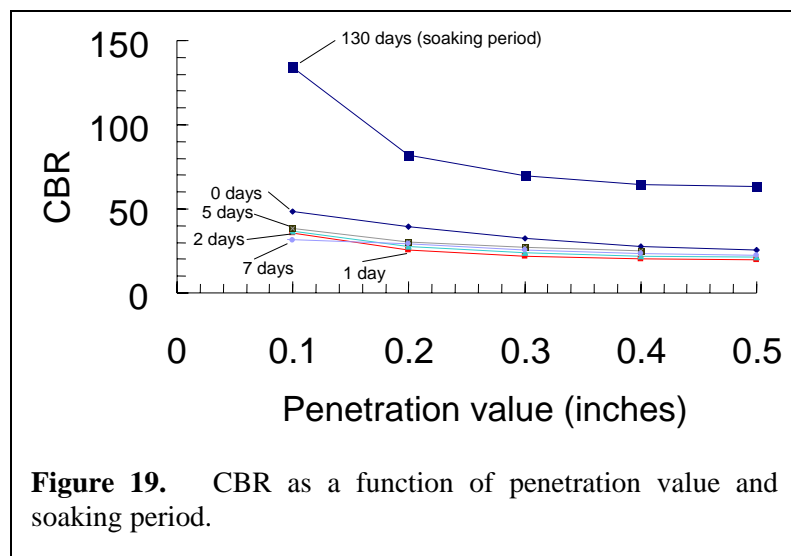


Figure 19. CBR as a function of penetration value and soaking period.

Long-Term Laboratory CBR Tests on Hydrated Lime-Soil Stockpile Mixtures

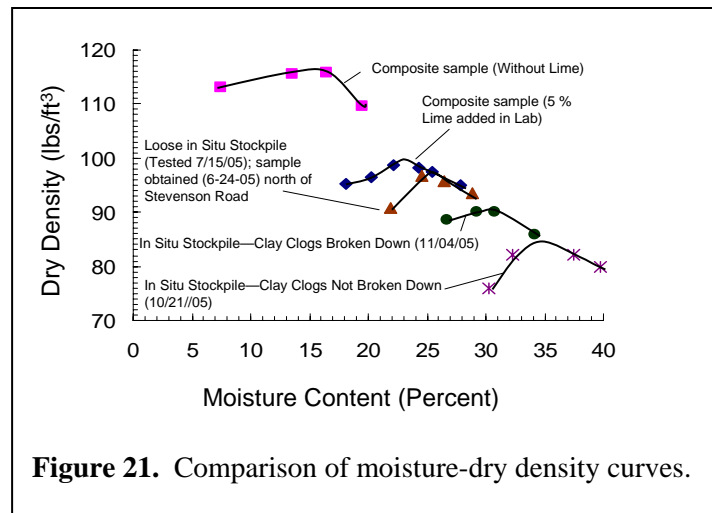
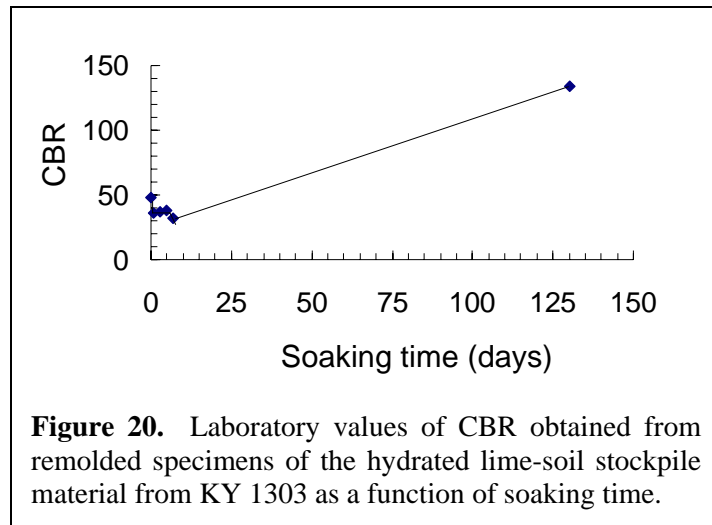
Long-term Laboratory CBR tests were performed on samples collected from the stockpile of hydrate Lime-soil mixture that was constructed during stabilization of the subgrade of KY 1303. Samples were remolded to 95 percent of maximum dry density and optimum moisture as determined from AASHTO T-99. Values of CBR and soaking periods are

summarized in Table 10. Specimens were tested after selected soaking periods. CBR values as a function of penetration values are presented in Figure 19. Long-term CBR values of the stockpile hydrated-lime mixture as a function of time are shown in Figure 20.

ANALYSIS

Comparison of Moisture–Dry Density Relationships

Samples were obtained from the stockpile at the time of construction. The samples were sealed in plastic bags until tested. Moisture-dry density relationships of the untreated subgrade soil and subgrade soil mixed with 5 percent of hydrated lime in the laboratory were compared previously in Figure 6. Those curves are compared in Figure 21 to moisture-dry density curves obtained



from compaction tests performed on samples obtained from the two stockpiles, which were constructed at the time of stabilization. A sample of the in situ stockpile built during construction was obtained June 24, 2005. This sample was tested October 31, 2005 (about 4 months after the stockpile was constructed) without breaking down the clay clods present in the sample. Values of maximum dry density and optimum moisture content of the in situ stockpile were 84.1 lbs/ft³ and 34.7 percent, respectively. The sample was retested and the clay clods were broken down before performing the compaction test. The maximum dry density increased to 90.2 lbs/ft³ and the optimum moisture content decreased to 30.0 percent, respectively. Values of maximum dry density and optimum moisture content of a sample obtained from the loose stockpile (from cuttings of the treated subgrade) north of Stevenson road were 96.7 lbs/ft³ and 24.9 percent. In all cases, maximum dry density and optimum moisture content of the treated samples were smaller and larger, respectively than the maximum

dry density and optimum moisture content of the untreated sample. This aspect is typical behavior of clay soils when treated with hydrated lime. The clays are usually transformed to a better material after treatment than the untreated soils.

In Situ CBR Values

In situ CBR values measured at the stockpile hydrated lime-soil subgrade of the Stevenson Road intersection seven days and 539 days after construction are compared to CBR values measured on an adjacent hydrated lime stabilized subgrade in Figure 22. Measurements on the adjacent treated (mainline roadway) subgrade were performed about 30 days after stabilization. The average value of the 539-day CBR value (only two measurements) was 16.7 while the average CBR value of the adjacent main roadway subgrade was 23.2. The average CBR value of the stockpile-built subgrade at the Stevenson Road intersection is about 28 percent lower than the average CBR value of the main roadway. The average CBR value of the two measurements at 7 days was about 6.8 and was lower than the average of the 539-day value of 16.7. This indicates that the CBR strength of the stockpile subgrade increased with increasing time.

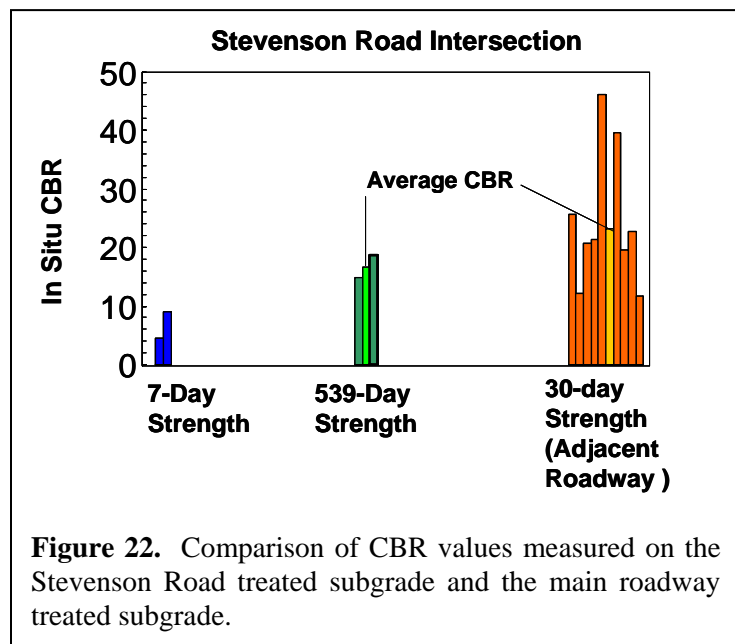


Figure 22. Comparison of CBR values measured on the Stevenson Road treated subgrade and the main roadway treated subgrade.

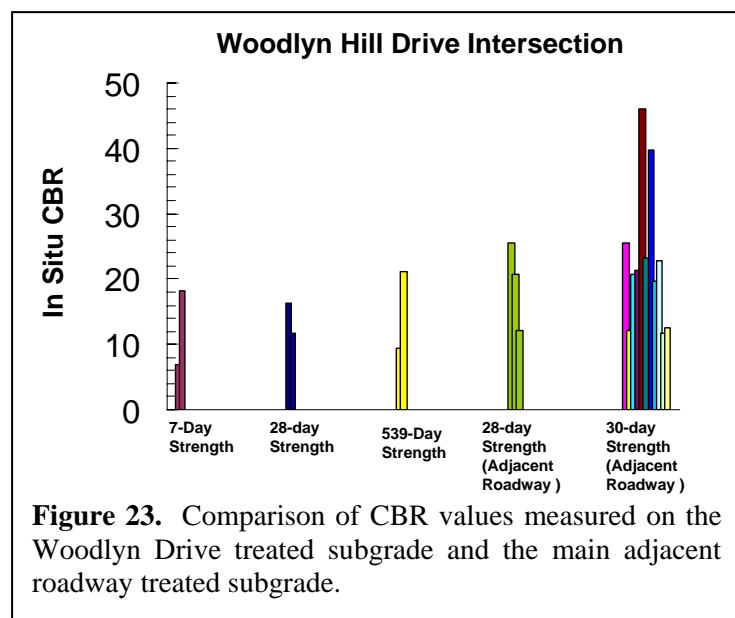


Figure 23. Comparison of CBR values measured on the Woodlyn Drive treated subgrade and the main adjacent roadway treated subgrade.

In situ CBR values of the hydrated lime stockpile-built subgrade measured at the Woodlyn Hill Drive 7, 28, and 539 days after construction are compared in Figure 23 to in situ CBR values of adjacent hydrated lime-treated subgrades of the main roadway measured at 28- and 30 days after construction. Average values were 12.7, 14.0, 15.3, 19.5, and 23.3, respectively. In situ CBR values of the main roadway ranged from about 11.8 to 46. Values of the stockpile-built subgrade ranged from 9.4 to 16.3 after 28 days. Although the in situ values of CBR of the stockpile-built subgrade are lower than the in situ values of the main roadway and laboratory values determined on stockpile specimens, the insitu values are very adequate, as shown in the next section, for providing substantial bearing strength for the flexible pavements at the intersections. The in situ values of the stockpile subgrade are some 7 to 16 times the laboratory CBR bearing strength (Table 1) and some 5 to 12 times the in situ CBR value (1.8) of untreated subgrades measured at several sites in this area and occurring at the 85th percentile value.

Comparison of Long-Term Values of Laboratory CBR and In Situ CBR

Results of CBR tests performed on remolded specimens of hydrated lime-soil stockpile material from the KY 1303 site are compared in Figure 24 to in situ CBR values measured 539 days after construction and to CBR values measured on the mainline stabilized subgrade. The laboratory CBR values are larger than the in situ CBR values of the main line roadway and the CBR values of the stockpile subgrade built from the stockpile material. Although the in situ values of the intersections subgrade are smaller, the magnitudes of the in situ CBR strength are more than adequate for providing strong subgrades to support the intersection pavements. The average CBR value (16) of the stockpile subgrade is only about 25 percent less than the average value of the main line roadway stabilized subgrade.

Table 11. R results from bearing capacity analysis of the two intersections constructed on the stockpile hydrated lime-soil mixture.

Asphalt Thickness (inches)	DGA Thickness (inches)	Hydrated Lime-Soil Stabilized Layer Thickness (inches)	Asphalt Strength (assumed from previous test data) ¹		Assumed Strength of Hydrated Lime-Soil Stabilized Layer		Assumed (Estimated) Strength of Untreated Subgrade		Factor of Safety ¹
			ϕ (deg.)	C (psf)	In Situ CBR	Undrained Strength, S_u ⁶ (psf)	Estimated CBR	⁵ Undrained Strength, S_u (psf)	
Stevenson Road Intersection									
20	5	0	43	varied	---	--	1.4	429	1.24
20	5	10	43	varied	4.5 ²	1,285	1.4	429	1.38
20	5	10	43	varied	9.1 ²	2,489	1.4	429	1.56
20	5	10	43	varied	14.8 ⁵	3,930	1.4	429	1.78
20	5	10	43	varied	18.6 ⁵	4,870	1.4	429	1.92
Woodlyn Hill Drive Intersection									
19	5	0	43	varied	--	--	1.4	429	1.19
19	5	10	43	varied	7.0 ³	1,946	1.4	429	1.45
19	5	10	43	varied	18.3 ³	4,797	1.4	429	1.92
19	5	10	43	varied	11.7 ⁴	3,152	1.4	429	1.65
19	5	10	43	varied	16.3 ⁴	4,303	1.4	429	1.84
19	5	10	43	varied	9.4 ⁵	2,566	1.4	429	1.55
19	5	10	43	varied	21.1 ⁵	5,483	1.4	429	2.02

1. See Hopkins, 1991 for methods of defining shear strength of asphalt pavement and computing the factor of safety from bearing capacity analysis.
2. In situ CBR at 8 days after construction.
3. In situ CBR 7 days after construction.
4. In situ CBR 28 days after construction.
5. In situ CBR 539 days after construction.
6. Value estimated using in situ CBR and Equation 1.

SUMMARY AND CONCLUSIONS

Field and laboratory investigations were performed to determine if a soil mixed with hydrated lime during routine lime subgrade stabilization could be mixed, stockpiled, and used later. Field trials were conducted on KY Route 499, (Turkey Foot Road) in Kenton County Kentucky. Results from field and laboratory tests and construction procedures were presented and documented.

Hydrated lime-soil mixtures were stockpiled and used to construct subgrades at two intersections at times after the completion of hydrated lime-soil stabilization of the mainline subgrade of KY route 499 in Kenton County Kentucky. To maintain traffic flow during hydrated lime-soil stabilization, the two intersections had to be left open. Approximately two months after construction of the hydrated lime-soil stockpile, the pavement at the Woodlyn Hill Drive intersection was removed and the stockpiled hydrated lime-soil was used to construct the top 10 inches of the subgrade. Similarly, at the Stevenson Road intersection, the pavement was removed and the top 10 inches of the subgrade was constructed about three months after construction of the stockpiled hydrated lime-soil mixture. In situ CBR values from tests conducted about 8 days, 28 days, and 20 months after construction of the stockpiled subgrades, ranged from 7.0 to 18.3, 11.7 to 8.2, and 9.4 to 21.1, respectively, for the Woodlyn Hill Drive site. In situ CBR of the stockpile subgrade at the Stevenson Road intersection ranged from 4.5 to 10.3 7 days after construction. Subgrade rutting occurred when the contractor prematurely started hauling and placing aggregate on the finished subgrade. The surface was rerolled and sufficient time was allowed for the subgrade to cure before placement of the pavement. About 20 months after construction, in situ CBR values ranged from 14.8 to 24.2.

Although the in situ CBR values of the stockpile subgrades of the two intersections were slightly smaller than in situ values of the mainline stabilized subgrades, the subgrades strengths were more than adequate to provide good stability for the flexible pavements. In situ CBR values measured after 20 months were about 5 to 13 times greater than the soaked, laboratory CBR (1.8 at the 85th percentile test value) of the untreated soils in this area. Bearing capacity analyses of the two intersections showed that the factors of safety ranged from 1.55 to 2.02. Based on past observations and analysis, values of this magnitude usually predict that flexible pavements will have good long-term performances. The use of stockpile hydrated lime-soil mixture was successfully used at the two intersections.

RECOMMENDATIONS

Based on the findings and conclusions of this study, the following recommendations are made:

- Further long-term monitoring, observations, and in situ testing of the Woodlyn Hill and Stevenson Road (Turkey Foot Road, Ky Route 1303) intersections are needed to establish the long-term performances of the flexible pavements and the subgrades constructed with stockpiled soil-hydrated lime mixtures.
- Addition sites should be evaluated. It is strongly recommended that another site in the Kope shale area, as well as other sites involving different types of soils, such as the red

clays of the Mississippian Plateau and the Bluegrass Physiographical Regions of Kentucky, should be selected for evaluation of the hydrated lime-soil stockpile concept.

- Create a special note, or provision, for stockpiled hydrated-lime mixtures and make the note available to insert into future highway projects, or future pilot projects. In drafting the special note, Standard Specifications, Edition 2004, pertaining to chemical stabilization of soil subgrades (using lime) should be followed as closely as practical (see Appendix). In particular, the following items might be noted:
 - In building the hydrated lime-soil stockpile, water may needed to be added to the mixture to maintain the moisture content of the material at or above its specified optimum moisture content at all times prior to curing and placement of the asphalt seal. A moisture-density test of the stockpile hydrated lime-soil mixture should be performed to determine the optimum moisture content and maximum dry density. Some drying of the hydrated lime-soil mixture stockpile may occur during the stockpile period and the moisture content of the stockpile material may be below optimum moisture content. At the time of reusing the stockpiled material, additional water may be needed to increase the moisture content to optimum, or slightly large.
 - Because water is needed to sustain chemical reactions occurring after applying hydrated lime, a continual application of water during mixing may be necessary even when the material is at optimum moisture.
 - Moisture content of the stockpile material should be carefully monitored when mixing and placement. Use of nuclear moisture-density gage or a “Speedy Moisture Apparatus” may provide a means of monitoring moisture content during construction. (A calibration curve for use in the field may be developed for the speedy moisture apparatus during the performance of the moisture-density test of the stockpile material.)
 - Space available at a given site where stockpiled hydrated lime-soil mixtures will be used greatly influences the type of equipment that can be used for watering, mixing, and compacting the stockpiled material. When space permits a disc might be used to mix the stockpiled material. If space is very limited, the teeth of a front-end loader might be used. This was successfully used at the sites described herein.
 - A vibratory sheepsfoot compactor may provide adequate compaction of the stockpiled hydrated lime-soil mixture. It is suggested that loose lift thickness should be limited to about 4 to 6 inches to obtain adequate compaction. A small test pad might be considered to determine the number of compactor passes needed to reach a specified dry density and determine the degree of compaction in relation to the maximum dry density.

- An asphalt seal should be placed on the stabilized subgrade constructed with stockpile soil-hydrated lime.
- Construction traffic should not be allowed on the subgrade constructed with stockpile soil-hydrated lime unless the subgrade can support the traffic and show no rutting. The dynamic cone penetrometer provides a rapid means of evaluating the in situ bearing strength, or CBR, of a treated or untreated subgrade and a correlation between CBR and Dutch Cone Penetration value has been developed (Hopkins and Beckham, 1994). When the CBR of the treated reaches a value of about 7, the subgrade usually has sufficient strength to maintain construction traffic without failure or rutting. Alternately, the Clegg Hammer and a correlation of CBR as a function of the Clegg Hammer value may be used to evaluate the subgrade.

ACKNOWLEDGEMENTS

This report is part of a research study examining the initial aspects for use of stockpiled hydrated lime-soil for reuse in subgrade construction. The Kentucky Transportation Center and Federal Highway Administration provided funding. Greg Kreutzjans, Branch Manager for Construction, District Six, initiated the study and is Chairperson of the Research Study Advisory Committee of the companion study. Rick Davis, James Minkley and Andy Durbin resident engineer, project engineer, and inspector, respectively, provided construction information and assistance in implementing the field trials. Eaton Asphalt was the contractor and voluntarily agreed to the field trials.

REFERENCES

- Molen, D. Memorandum *Geotechnical Engineering Report Kenton County, KY 1303 Turkey Foot Road, Section 1 (KY 1303)*, Transportation Cabinet, Division of Materials, Geotechnical Branch, Report NO. R-47-98, December 1998.
- Molen, D. Memorandum *Geotechnical Engineering Report Kenton County, KY 1303 Turkey Foot Road, Section 2 (KY 1303)*, Transportation Cabinet, Division of Materials, Geotechnical Branch, Report No. R-48-98, December 1998.
- Hopkins, T.C., and Allen, D. L. (1986). "*Lime Stabilization of Pavement Subgrade Soils of Section AA-19 of the Alexandria-Ashland Highway*," Research Report 86-24, University of Kentucky Transportation Center, College of Engineering, Lexington, Kentucky.
- Hopkins, T.C. (1987). "*Lime Stabilization of Kentucky Soils*," University of Kentucky Transportation Center, College of Engineering, Oral presentation to the National Lime Conference, Lexington, Kentucky.
- Hopkins, T.C. Hunsucker, D., and Sharpe, G.W. (1988). "*Highway Field Trials of Chemically Stabilized Soil Subgrades*" Proceedings of the Ohio River Valley Soils Seminar XIX, Lexington, Kentucky.
- Hopkins, T.C. "*Bearing Capacity Analysis of Pavements*," KTC-91-8, February 1991.

- Hopkins, T.C. Beckham, T.L.; and Hunsucker, D. Q. “*Modification of Highway Soil Subgrades,*” University of Kentucky, Kentucky Transportation Center, June 1994.
- Hopkins, T.C. Beckham, T.L.; Sun, C., Ni, B., and Butcher, B. “*Long-Term Benefits of Stabilizing Subgrades,*” University of Kentucky, Kentucky Transportation Center, June 2002.

APPENDIX

SECTION 208 $\frac{3}{4}$ CHEMICALLY STABILIZED ROADBED

(Specifications from the Kentucky Transportation Cabinet, Standard Specifications 2004 Edition.)

(Note: Shaded area below: Soil-Cement is not considered applicable at this time to using as a stockpiled material and this text does not apply.)

SECTION 208 ¾ CHEMICALLY STABILIZED ROADBED

208.01 DESCRIPTION. Construct roadbed stabilization by uniformly mixing the specified chemical stabilizer, cement or lime, with the roadbed material, and moistening and compacting the resulting mixture.

208.02 MATERIALS AND EQUIPMENT.

208.02.01 Cement. Select any type conforming to Section 801 except Type IV. Use the same type cement throughout the work.

208.02.02 Lime. Select from the Department's List of Approved of Materials for Lime (Hydrated and Quicklime).

208.02.03 Asphalt Curing Seal. Conform to Section 806. Use RS-1, SS-1, SS-1h, or Primer L.

208.02.04 Water. Conform to Subsection 803.

208.02.05 Sand. Use natural, crushed, or conglomerate conforming to Section 804.

208.03 CONSTRUCTION.

208.03.01 Temperature and Weather Limitations. Only apply stabilizer when the ambient air temperature is at least 40 °F in the shade and rising. Do not mix stabilizer with frozen soils or with soil containing frost.

208.03.02 Preparation of Existing Roadway. Before proceeding with other construction operations, grade and shape the roadway to the grades, lines, and cross section required for the completed roadway. Remove any organic material, such as roots, and any rocks larger than 4 inches from the material to be stabilized. Ensure that the elevation of the subgrade before stabilization is according to Subsection 204.03.10. When using lime, scarify to the depth required for the stabilization before application. Carefully control the depth of stabilization so the surface of the roadbed below the scarified material remains undisturbed and conforms to the established cross section.

208.03.03 Application of Chemical. Apply the quantity of stabilizer and mix to the depth the Contract specifies or as the Engineer directs. The Department reserves the right to increase or decrease the quantity of stabilizer used and depth of treatment as deemed necessary by the Engineer.

The Department will not accept any stabilizer that has been exposed to the open air for a period of 4 hours or more for payment. Replace any quantity lost due to rain or wind. Only allow

traffic and equipment required for spreading, watering, or mixing on the spread stabilizer. Prepare, transport, and distribute stabilizer on the roadbed, and mix it with the soil in a manner that will not cause injury, damage, discomfort, or inconvenience to individuals or property. Do not apply stabilizer when wind conditions, as determined by the Engineer, are such that blowing stabilizer becomes hazardous to traffic, workmen, adjacent property, or results in adverse impact upon the public. Do not apply dry chemicals pneumatically.

A) Cement. Spread the specified quantity of cement required for the full depth of treatment uniformly over the surface in one application.

Only apply cement to an area of such size that all operations, dry mixing through cutting final grade, are completed within 6 hours. Perform all operations in a continuous manner and complete all operations during daylight hours.

B) Lime. Only apply lime to an area of such size that all primary mixing operations are completed within the same day. Perform all primary-mixing operations during daylight hours. Spread the lime by any of the following methods:

1) Slurry made with hydrated lime. Mix with water in agitating equipment and apply on the scarified area through distributing equipment. Use a distributor equipped to provide continuous agitation to ensure a uniform mixture from the mixing site until applied to the roadbed. 2) Slurry made by slaking quicklime at or near the project site. Gain approval of all equipment and procedures before beginning work.

3) Dry hydrated or quicklime when specified or when approved in writing by the Engineer. Use only when saturated soil conditions exist and the slurry method would worsen the situation or when weather conditions prohibit the use of slurry. Uniformly spread the lime without excessive loss. The Engineer will not require scarifying of the roadbed before placing dry hydrated or quicklime.

208.03.04 Mixing.

A) Cement.

1) Dry Mixing. Immediately after distributing, mix the cement with the soil for the full depth of treatment. Take care to avoid mixing cement below the specified depth. Continue mixing until the cement has been sufficiently blended with the soil to prevent forming cement balls when applying water.

2) Moist Mixing. Immediately after the soil and cement have been dry mixed, uniformly apply and incorporate water into the mixture. Apply the water uniformly using pressure-distributing equipment. The Department will allow application of water during dry mixing when introduced through the mixing machine. Immediately after mixing, the Engineer will determine the moisture content of the soil cement mixture. When directed by the Engineer, uniformly apply additional water. Avoid concentration near the surface when incorporating water into the soil and cement mixture. After adding the last increment of water, continue mixing until 100 percent of the soil passes a one-inch sieve and at least 80 percent of the soil passes a No. 4 sieve, exclusive of gravel or stone retained on these sieves. After completing the water application and mixing, ensure that the moisture content of the mixture is not below the specified optimum moisture or more than 2 percent above the specified optimum moisture, and is less than the

quantity that causes the roadbed to become unstable during compaction and finishing. Do not allow any mixture of soil and cement that has not been compacted and finished to remain undisturbed for more than 30 minutes. When the soil-cement mixture is wetted by rain to the extent that the moisture content exceeds the tolerance specified herein, reconstruct the entire section.

B) Lime. During the period after the application of lime until completion of preliminary curing, add water to maintain the moisture content of the material at or above its specified optimum at all times. Because water is needed to sustain chemical reactions occurring after applying the lime, a continual application of water during mixing may be necessary even when the material is at optimum moisture when mixing begins.

1) **Primary Mixing.** Immediately after spreading the specified quantity, thoroughly mix the lime into the soil for the full depth of treatment.

Complete the primary mixing operation within 4 hours after applying lime. At this time, the result shall be a homogeneous, friable mixture of soil and lime, free from clods or lumps exceeding 2 inches in size.

After primary mixing, shape the lime treated layer to the approximate cross section and lightly compact to minimize evaporation loss. Crown the surface to provide surface drainage.

2) **Preliminary Curing (mellowing).** Following primary mixing, allow 48 hours for the roadbed to cure (mellow). The Department will allow remixing after 24 hours if the gradation requirement is obtained. The characteristics of the soil, temperature, and rainfall may influence the mellowing period necessary. During the mellowing period, keep the surface of the material moist to prevent drying and cracking.

3) **Final Mixing and Pulverizing.** Within 72 hours after the preliminary curing, completely mix and pulverize the roadbed to the full depth of stabilization. Continue final mixing until 100 percent of the soil, exclusive of rock particles, pass the one inch sieve and at least 50 percent pass a No. 4 sieve.

208.03.05 Compaction and Surface Finish. Compact the mixture uniformly for its full depth, to at least 95 percent of the maximum density determined according to KM 64-511. The Engineer will determine the density. Compact continuously until completing the final compacted surface.

After curing of the roadbed is completed, correct any stabilized roadbed that does not conform to the surface tolerances of Subsection 204.03.10 by leveling approved by the Engineer. Only remove material to level in small, isolated spots. Discard any material removed from the cured roadbed.

208.03.06 Curing and Protection. After finishing the roadbed, protect it against drying by applying an asphalt curing seal.

Apply the curing seal as soon as possible, but no later than 24 hours after completion of finishing operations. Keep the finished roadbed moist, by continuous sprinkling if necessary, until applying the curing seal. Only apply the asphalt material to a roadbed surface that is dense, free from loose extraneous material, and that contains sufficient moisture to prevent penetration of the asphalt material.

Provide a curing seal consisting of the asphalt material specified and uniformly apply the curing seal at the rate of approximately 2.0 pounds per square yard. The Engineer will determine the actual rate and application temperature of asphalt material. Apply the curing seal in sufficient quantity to provide a continuous membrane over the roadbed. To avoid excessive runoff, apply the seal in 2 or more applications when directed or allowed, making each application as soon as possible after the previous application.

Do not allow any traffic or equipment on the finished surface until 7 days above 40 °F curing is completed or the roadbed cores achieve a minimum strength requirement of 80 psi. The Department will only require cores when the Contractor requests a shortened curing time. When a shortened curing time is requested, furnish cores to the treated depth of the roadbed at 500 feet intervals for each lane. The Department will test the cores using an unconfined compression test. If any damage occurs before curing is complete, immediately reseal the damaged area.

If the asphalt material is tacky or sticky, apply a sand blotter material at a rate of approximately 5 pounds per square yard, when the Engineer directs, to avoid damage to the seal or to avoid tracking material onto other facilities.

After the curing period, protect any finished portion of the roadbed that equipment travels on from being marred or damaged.

Repair any damage caused by freezing.

Make every reasonable effort to completely cover the stabilized roadbed with the specified pavement courses before suspending work for the winter months. If the stabilized roadbed is not completely covered by the specified pavement courses, determine and perform any further work necessary to protect and maintain the uncompleted work during the winter months. Perform any work necessary to acceptably repair or restore the uncompleted work before the beginning of spring paving operations. The Department may require cores to be taken to verify that the stabilized roadbed was not unreasonably damaged from unprotected winter cycles. Perform all work necessary to protect, maintain, or repair the stabilized roadbed subject to the Engineer's approval.

208.03.07 Maintenance. Maintain the entire roadway within the limits of the Contract, for the duration of the Contract. Keep the roadway continuously intact by immediately repairing any defects that may occur either before or after completing the stabilized roadbed, at no expense to the Department. When making repairs, completely restore the uniformity of the surface and durability of the repaired portion.

208.04 MEASUREMENT. The Department will not measure extra materials, methods, or work for payment when used to protect, maintain, or repair uncompleted work.

208.04.01 Cement. The Department will measure the quantity in tons. The Department will not measure cement for payment when exposed to the open air for a period of 4 hours; lost due to rain or wind; or used for corrective or reconstructive work.

208.04.02 Lime. The Department will measure the quantity in tons. The Department will not measure lime for payment when exposed to the open air for a period of 4 hours; lost due to rain or wind; or used for corrective or reconstructive work.

When quicklime is furnished for slurry application, the Department will measure the quantity in tons at 1.25 times the actual quantity. When hydrated or quicklime is furnished for dry application, the Department will measure the actual quantity applied to the roadbed.

208.04.03 Cement Stabilized Roadbed. The Department will measure the quantity in square yards. The Department will not measure corrective or reconstructed work for payment. The Department will not measure hot-mixed asphalt for payment when used for corrective leveling. The Department will not measure water for payment and will consider it incidental to this item of work.

208.04.04 Lime Stabilized Roadbed. The Department will measure the quantity in square yards. The Department will not measure corrective or reconstructed work for payment. The Department will not measure hot-mixed asphalt for payment when used for corrective leveling. The Department will not measure water for payment and will consider it incidental to this item of work.

208.04.05 Asphalt Curing Seal. The Department will measure the quantity in tons. The Department will not measure corrective work for payment.

208.04.06 Concrete Sand for Blotter. The Department will measure the quantity in tons.

208.05 PAYMENT. The Department will make payment for the completed and accepted quantities under the following:

Code Pay Item Pay Unit

2542 Cement Ton
 0014 Lime Ton
 0008 Cement Stabilized Roadbed⁽¹⁾ Square Yard
 0013 Lime Stabilized Roadbed⁽¹⁾ Square Yard
 0358 Asphalt Curing Seal Ton
 2702 Sand for Blotter Ton

(1) When the Engineer increases the depth of treatment, the Department will increase the quantity for that portion of the work as follows:

*4 inches additional, multiply by 1.33
 8 inches additional, multiply by 1.50*

The Department will consider payment as full compensation for all work required under this section.

For more information or a complete publication list, contact us at:

KENTUCKY TRANSPORTATION CENTER

176 Raymond Building
University of Kentucky
Lexington, Kentucky 40506-0281

(859) 257-4513
(859) 257-1815 (FAX)
1-800-432-0719
www.ktc.uky.edu
ktc@engr.uky.edu

The University of Kentucky is an Equal Opportunity Organization