Research Report
KTC-05-01/SPR 270-03-1I

KENTUCKY TRANSPORTATION CENTER

College of Engineering

SWELLING PAVEMENTS: KY 499 ESTILL COUNTY

UNIVERSITY OF KENTUCKY

UNIVERSITY OF KENTUCKY
College of Engineering
Kentucky Transportation Center

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.

We Value...

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

For more information or a complete publication list, contact us

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

Research Report KTC-05-01/SPR – 270-03-1I

Swelling Pavement: KY 499 Estill County

By

Tony L. Beckham
Research Geologist

Tommy C. Hopkins
Program Manager

Kentucky Transportation Center
College of Engineering
University of Kentucky

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

March 2005

1. Report No. KTC-05-01SPR270-03-1I	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **Study Title: Characteristics and Engineering Properties of the Soft Soil Layer at the Top of Highway Subgrades** **Report Title: Swelling Pavement: KY 499 Estill County**		5. Report Date March 2005 6. Performing Organization Code 8. Performing Organization Report No. KTC-05–01/SPR-03270-1I
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-03-270
12. Sponsoring Agency Name and Address Kentucky Transportation Cabinet 200 Mero Street Frankfort, KY 40622		13. Type of Report and Period Covered Interim 14.Sponsoring Agency Code
15. Supplementary Notes Prepared in cooperation with the Federal Highway Administration, US Department of Transportation		

16. Abstract

A field and laboratory investigation was performed to determine why excessive swelling was occurring on a pavement section of KY Route 499 that was about four years old. Swelling occurred on a section of roadway that had been constructed with a hydrated lime-stabilized subgrade. As shown by laboratory swell tests, swelling of the pavement was due to the absorption of water and expansion of the compacted clay shale subgrade. Results of laboratory swell tests showed that the hydrated lime stabilization of the shale actually reduced swelling. Chemical reactions between calcium, present in the hydrated lime, and sulfates, which were present in small amounts did not contribute to swell.

17. Key Words Pavement Swell, Subgrade, Lime Stabilization, Shale		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 14	22. Price

Form DOT 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Construction of the Irvine Bypass in Estill County, an extension of existing KY Route 499, was completed in September 2000. The route is a connector between KY Routes 52 and 89 (Milepoint 7.741 to 9.215) northwest of Irvine as shown in Figure 1.

The resident engineer and construction inspectors with the Kentucky Transportation Cabinet, indicated pavement swell (or heave) was observed during construction and has continued since. One pavement section on the northeast end was rebuilt due to swell before construction was complete. The Kentucky Transportation Cabinet requested that the Kentucky Transportation Center investigate the swelling pavement as a part of an ongoing research study examining the effect of saturated subgrades on pavement quality.

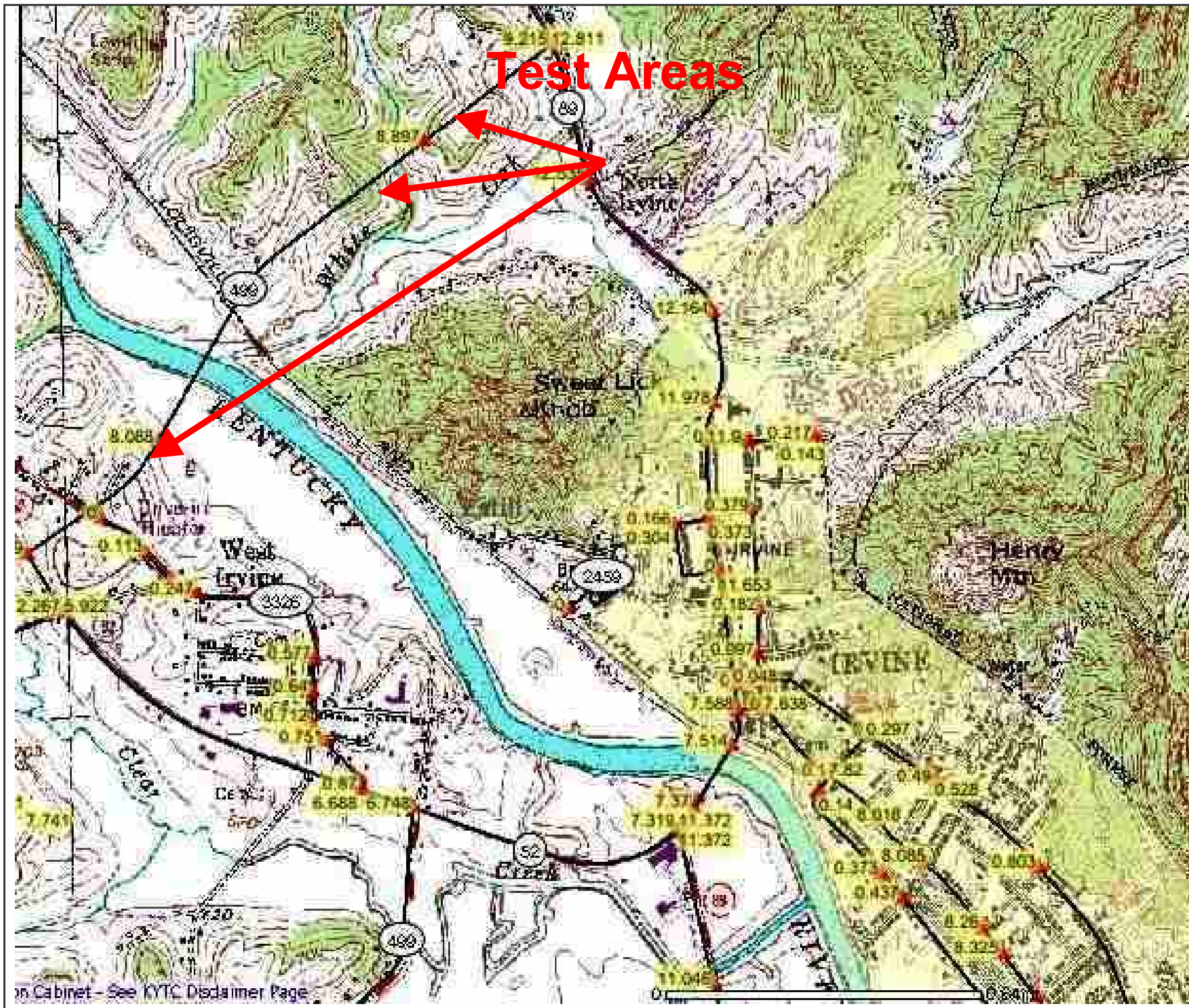


Figure 1. Site Map (from Kentucky Transportation Cabinet Division of Planning Interactive Mapping Web Site)

The roadway was constructed in areas where the Crab Orchard shale formation is the predominant bedrock. This formation is notorious for causing highway problems such as excessive embankment settlement, cut and fill slope failures, and swelling when exposed to moisture. Swelling problems associated with Crab Orchard shale had occurred before on I-64 in Bath County (Hopkins, et al 1973) and KY 9 in Lewis County. The pavement was removed and the shale fill and subgrade were excavated and replaced with several feet of crushed stone at the I-64 site. Embankment and cut slope problems have been reported in highways constructed where Crab Orchard shale is present. Soils formed from the Crab Orchard shale have very poor engineering properties. Cut slope problems and pavement swelling are also occurring on I-265 in Jefferson County where the New Providence shale formation is the predominant bedrock. The New Providence shale is similar to the Crab Orchard shale and both types of clay shales exhibit very poor engineering properties.

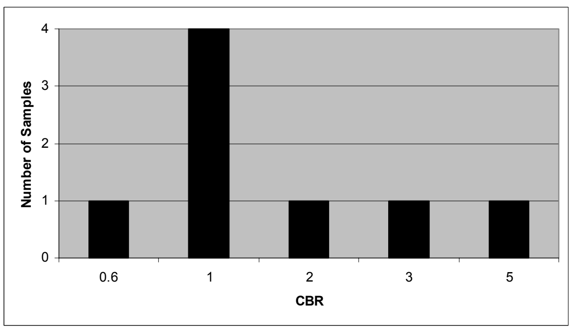


Figure 2. CBR Values from Geotechnical Report

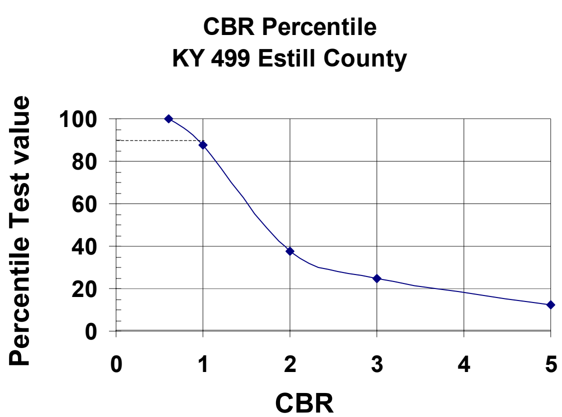


Figure 3. Percentile Test Value as a Function of CBR Values from the Geotechnical Report

The geotechnical report prepared for the project and issued by the Kentucky Transportation Cabinet's Division of Materials Geotechnical Branch (1997) recommended subgrade lime stabilization because of the low CBR (soaked) values associated with the soils. Five out of eight CBR samples tested had CBR values of 1 percent or less, six out of eight had two percent or less, and 7 of 8 had 3 or less. Only one CBR sample was greater than 3 and that value was only 5 percent. Hydrated lime stabilization was used on most of the project. Initial results from laboratory CBR tests are shown in Figure 2. The percentile test value as a function of CBR laboratory tests is shown in Figure 3. At the 85^{th} test value the CBR value is only 1. Normally the 85the percentile test value is an acceptable selection for pavement design. Past research (Hopkins 1991) has recommended using chemical stabilization to improve CBR strength when the CBR value is less than about 7. The use of chemical stabilization (hydrated lime) was fully justified in this case.

Lime and other types of chemical stabilization have been used to improve the bearing capacity of highway subgrades for many years. The roadway was constructed through an area where the Crab Orchard Shale formation, shale with very poor engineering properties, is the predominant bedrock type. The New Albany shale is also present. Both of these formations contain pyrite, but the New Albany shale contains more pyrite, and possibly, other sulfur bearing minerals than the Crab Orchard Shale. Oxidation of the sulfur compounds may produce sulfates that can react with calcium, which is present in the hydrated lime, and cause swelling.

Portland cement was used to stabilize the subgrade where KY 89 was relocated to intersect the new route, and on a small reconstructed section on the northeast end of KY 499. Lime kiln dust was used for subgrade stabilization at both bridge approaches

FIELD TESTING AND OBSERVATIONS

A field and laboratory investigation was performed to determine the cause of the pavement swelling. There was some concern the swelling may be due to sulfates in the bedrock reacting with calcium present in the hydrated lime stabilizer causing the swelling. Pavement swelling has occurred in the past when byproducts containing sulfates and hydrated lime were used as a subgrade chemical stabilizer. Swelling problems have been reported in other states where hydrated lime was used to stabilize soils containing sulfates. It was also believed the swell may also be due to the poor engineering properties of the Crab Orchard shale, or a combination of both.

Field-testing was performed in cut sections where most of the swelling was observed during the initial field reconnaissance. The areas of pavement swelling were humps that measured a few inches in height. Generally, the humped areas occur perpendicular to the roadway alignment in cut sections. Swelling was also noticed in cut sections parallel to the roadway at the shoulder drainage ditch interface (right side photo in Figure 4).

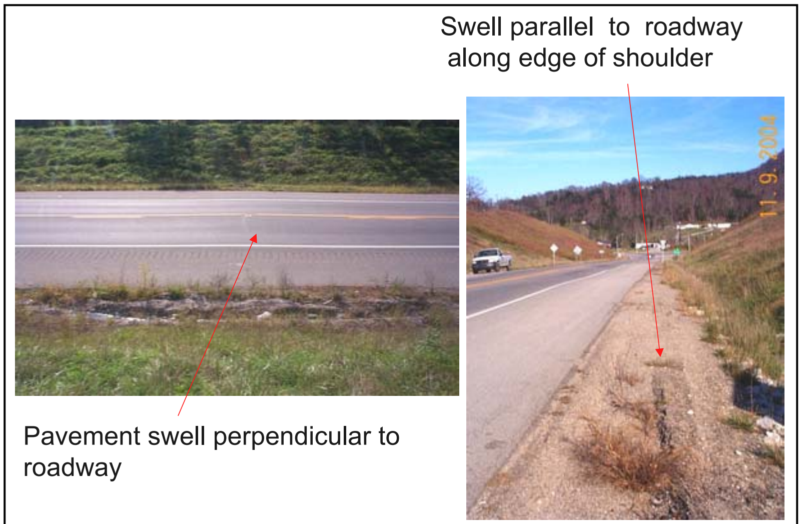


Figure 4. Photographs of Observed Swell

Standing water was observed in drainage ditches on both sides of the road at the central test site. The ditch was not effective due to slumping of the cut slopes and swelling from the shoulders. Drainage was better at the other two sites (the two on each end). These drainage ditches were on steeper grades and constructed with channel lining.

After completion of field-testing by the University of Kentucky Transportation Center (UKTC) personnel in December of 2004, the pavement was milled in areas where swelling was observed to be the most severe.

Field investigations consisted of obtaining cores of the asphalt pavement to determine actual thickness. Standard penetration tests were performed to determine the thickness of the aggregate base and stabilized subgrade. In situ field California Bearing Ratio (CBR) tests were performed near the top of the hydrated lime stabilized subgrades and on the soil below the stabilized layer. Testing was performed at three locations. Two of the locations were north of the Kentucky River, in cut sections, where swelling was large. The third location was in a cut section south of the Kentucky River, where swelling was observed, but did not appear to be as large as observed in the northern locations. The approximate test locations are shown in Figure 1. Subgrade samples were obtained for laboratory testing and chemical analysis.

The lowest field CBR values obtained on top of the soil-hydrated lime subgrade were 47.1 and 50.6 percent at the two locations north of the Kentucky River. A CBR test conducted on the subgrade below the stabilized layer was only 2.2 percent.

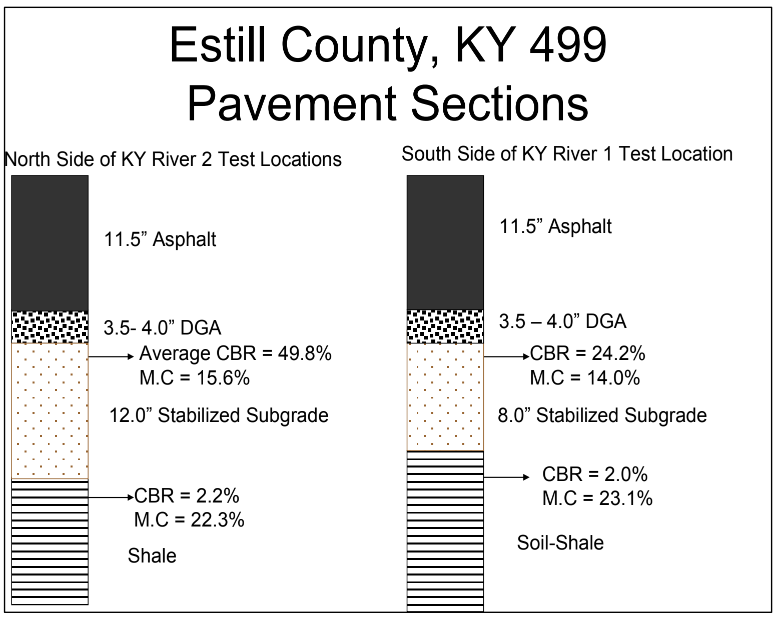


Figure 5. Pavement Sections and In Place CBR Values with Moisture Contents

The stabilized subgrade and layer below the stabilized subgrade at the site south of the Kentucky River were 24.2 and 2.0 percent, respectively. At all locations, the in situ CBR tests show that hydrated lime stabilization was very effective in improving the subgrade bearing capacity. CBR values of the stabilized subgrade were some 12 to 23 times larger than the untreated subgrade. Results from field CBR tests are shown in Figure 5.

Pavement thickness was determined from asphalt cores and standard penetration tests. Thickness of the asphalt concrete pavement north of the Kentucky River was 11.5 inches. The Dense Graded Aggregate (DGA) base was 3.5 to 4 inches thick, and the hydrated lime stabilized subgrade was 12 inches thick. The subgrade north of the river was constructed with green shale. At the site located south of the river, the asphalt and DGA thicknesses were the same as north of the river. The stabilized subgrade was thinner, about eight inches thick. Pavement sections are summarized in Figure 5. Thickness of the 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 in a high pH environment, which is the case for hydrated lime stabilized subgrades.

Settlement points were established at the three test locations after the pavement was milled. Points were set at one-foot intervals across the roadway, perpendicular to the alignment. Elevations will be obtained periodically to determine the rate of swelling. Initial elevations and some subsequent data has been obtained but is not sufficient to predict swell rates. Changes in

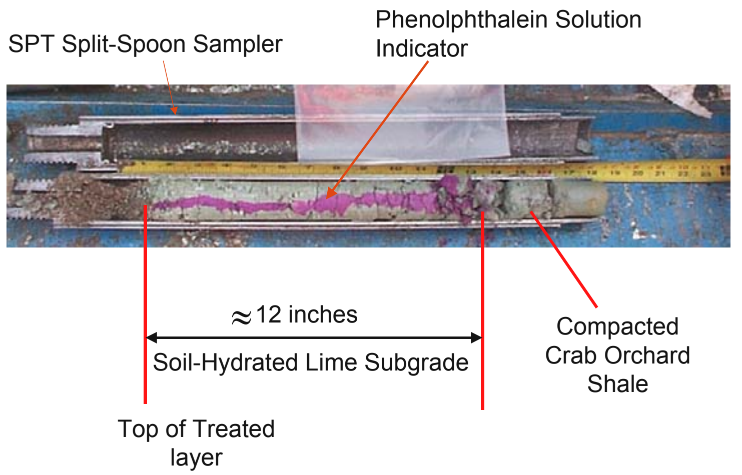


Figure 6. Photograph of Phenolphthalein Indicator Applied to Hydrated Lime Stabilized Soil

elevations are being monitored with conventional surveying methods and with survey grade global positioning system (GPS) equipment. No swelling patterns have been established to date. Hopefully, the point locations can be reestablished using the GPS equipment if they are destroyed by pavement milling or patching.

LABORATORY TESTING

CBR and Swell Tests

Moisture-density relations and CBR tests were performed on disturbed samples of the shale and on a shale sample mixed with five percent (by dry mass) hydrated lime. The tests were performed following procedures used by the Kentucky Transportation Cabinet, Division of Materials, Geotechnical Branch, except the soaking periods of the CBR specimens were longer than specified by their CBR standard testing procedure.

CBR tests were allowed to soak longer than the time specified by the standard procedure for two reasons:

1) The specimen, which was only shale, continued swelling beyond the 14-day maximum soaking period specified by the standard procedure, and

2) Any delay in swelling, which may occur (especially in the shale-hydrated lime sample), needed to be measured.

There was some concern that the shale-hydrated lime sample may have a delayed time period of swelling due to sulfates in the soil reacting with calcium present in the hydrated lime. Previous research (Hopkins et al., 1994, Hunsucker et al. 1) has shown a delayed swell period occurs when soil is mixed with hydrated lime and materials containing sulfates.

Both CBR specimens were soaked for a total of 18 days--the time required for the non-stabilized sample to stop swelling. Values obtained from the (soaked) CBR tests were 0.8 and 20.6 percent for the shale and shale-hydrated lime mixture, respectively. Those test values confirmed CBR measurements in the field. In situ values of CBR obtained for the hydrated-lime-compacted shale subgrade were 24.2, 47.1, and 50.6. In situ values of the compacted shale were only 2.0 and 2.2. Chemical stabilization using hydrated lime vastly improved the bearing strength of the clayey shale subgrade. Swell of the compacted shale sample was almost 20 percent of the original sample height while swell of the compacted shale-hydrated lime sample was only about three percent, as shown in Figure 7.

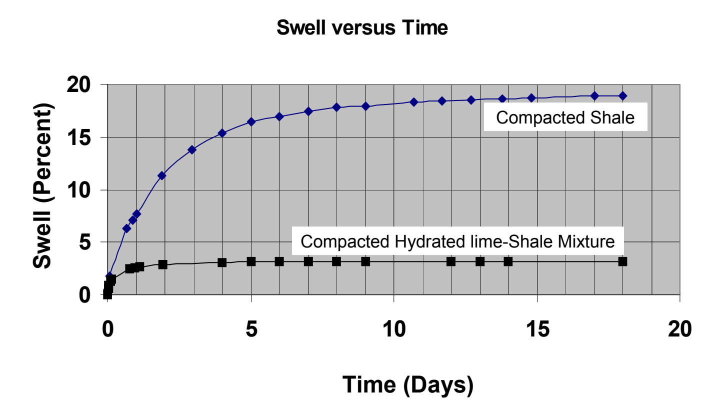


Figure 7. Swell Versus Time, KY CBR Test Samples

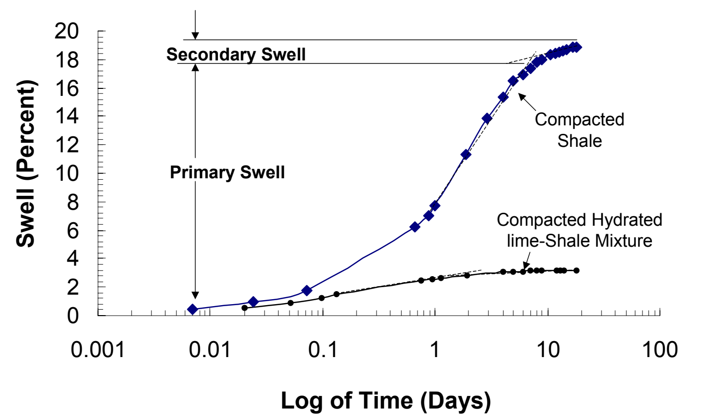


Figure 8. Swell (in percent) as a Function of the Logarithm of Time

Both samples had the same surcharge mass during soaking (17.8 lbs.) which created a surcharge pressure of 0.63 psi on both samples. Swell was plotted against the log of time in hours to determine when primary swell had stopped for the two samples (Figure 8). Primary swell stopped after about (7 days) for the compacted shale specimen, as shown in Figure 8. Primary swell in the compacted shale-hydrated lime specimen occurred in less than about 1.5 days and was very small (about 3 percent). However, secondary swell of the compacted shale specimen continued after primary swell while the secondary swell of the compacted shale-hydrated lime ceased after completion of primary swell, that is, secondary swell was zero.

Swell Pressure Tests

Swell pressure tests were also performed on the compacted shale and shale-hydrated lime mixture. The procedures used to perform these tests are described here because it is not a standard referenced procedure. The samples were mixed and compacted to 95 percent of maximum dry density at optimum moisture content to simulate initial compaction. Field compaction specifications require a minimum of ninety five percent maximum dry density and ± two percent of optimum moisture content.

The specimens were compacted in a CBR mold with a perforated bottom to allow moisture penetration. A load cell was placed between the swell plate and a metal beam attached to a frame holding the mold containing the compacted soil sample. Two of the swell pressure tests were placed into water immediately after compacting. A third test was performed on a shale lime mixture, which was compacted into a CBR mold and sealed in plastic, three days before soaking.

Previous research (Hopkins, et al, 1994) has shown that sealing chemically stabilized compacted samples and allowing them to cure a few days will reduce the swell. This allows cementious reactions required to develop bonds between the soil particles time to develop. This is why curing periods up to seven days are specified after final compaction of stabilized subgrades. A schematic and photographs of the swell pressure apparatus are shown in Figures 9 and 10,

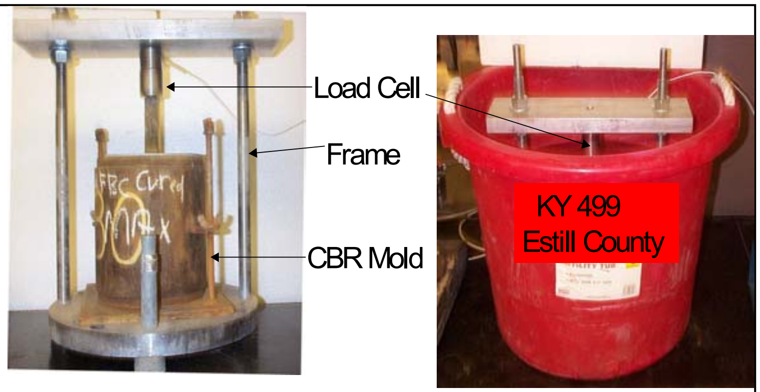


Figure 9. Photograph of Swell Pressure Apparatus, Before and During Soaking

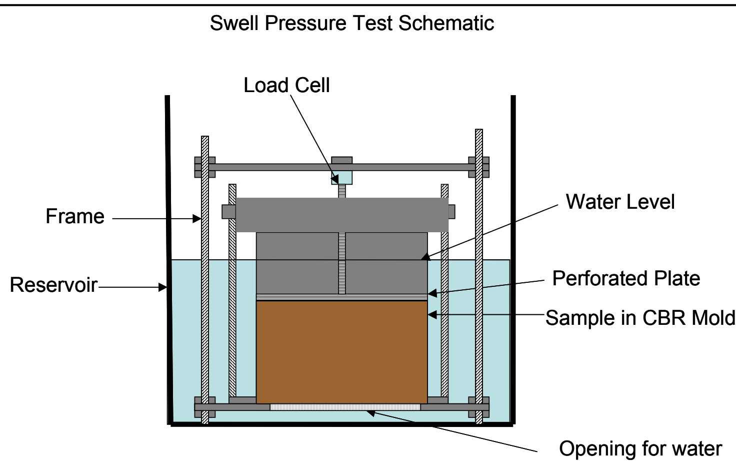


Figure 10. Schematic of Swell Pressure Apparatus

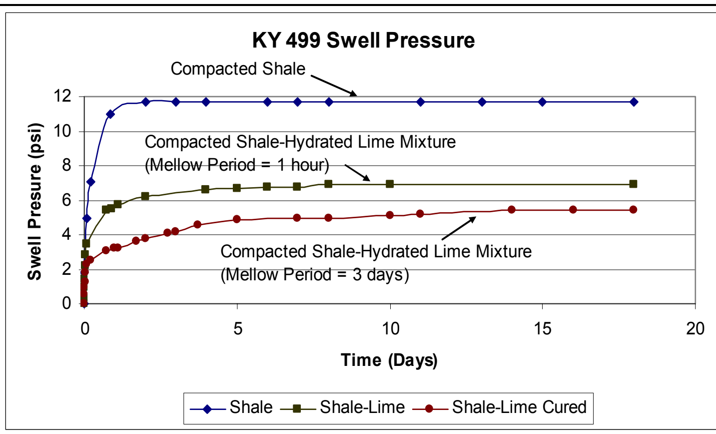


Figure 11. Swell Pressure as a Function of Time

respectively. The vertical movement of the specimen is completely restrained, that is, vertical strain is zero.

The unit weight of the total asphalt concrete was 146.6 lbs/ft^3. The unit weight of the stabilized subgrade was 134.0 lbs/ft^3. These values were determined from core samples obtained from the roadway. Assuming a unit weight of 140.0 lbs/ft^3 for the DGA base, the total surcharge for a typical pavement section, shown in Figure 2. (11.5 inches asphalt, 4.0 inches DGA and 12 inches lime stabilized subgrade) on the non-stabilized subgrade would be 321 lbs/ft^2 or 2.2 psi.

Results from the swell pressure tests showed that the compacted non-stabilized shale exerted a stress of almost 12 psi. Stabilizing the shale with five percent hydrated lime and placing the compacted sample into water with no curing period reduced this by 5 psi. Allowing the hydrated lime stabilized shale to cure for three days in a sealed container reduced swell pressure to 5.6 psi (Figure 11). A longer mellow period would tend to reduce this further. In the field, the hydrated-lime stabilized would have a minimum of seven days to cure.

The samples were compacted in a CBR mold, which has a perforated bottom allowing water to penetrate the sample from below. The inside of the mold was lined with a thin Mylar drafting film to reduce friction between the sample and side of the mold. A perforated CBR swell plate was placed on top of the compacted samples permitting moisture to enter the sample from the top. The compacted sample and mold was then placed in a frame fabricated with a metal beam attached to a bottom with threaded rods. The load cell was threaded into the top metal beam. The load cell and beam were positioned so the load cell would contact a threaded rod extending from the swell plate on top of the sample. The bottom of the frame is perforated allowing water to reach the sample from below. The frame and mold were placed in a reservoir and water was maintained above the top of the sample and below the load cell.

Soil Classification Tests

Soil classification tests – liquid and plastic limits, specific gravity, and particle size - were performed on stabilized and non- stabilized samples obtained during field-testing. Based on the Unified Soil and AASHTO Classification Systems, stabilizing the soil with hydrated lime changed the properties of the compacted shale from lean clay, (CL or A-7-6) to sand and gravels (SM and SW or A-2-7), respectively. Results of classification tests are summarized in Table 1.

Table 1. Soil classification test results

Sample ID	**LL (%)**	**PL (%)**	**PI (%)**	**Percent**				**Classification**	
				Gravel	Sand	Silt	Clay	AASHTO (GI)	Unified
Site 1 and 2 Non-Stab. Shale	41	25	16	5	10	52	33	A-7-6 (14)	CL
Site 1 Hole 4 Stabilized	42	28	14	90	5	4	1	A-2-7 (0)	SW- SP
Site 2 Hole 9 Stabilized	47	32	15	34	32	24	10	A-2-7 (1)	SM
Site 3 Hole 13 &15 Non-Stab.	45	24	21	8	20	39	33	A-7-6 (14)	CL

EVALUATION OF PAVEMENT CONDITION BASED ON RIDEABILITY INDICES

Evaluation of the pavement condition of Ky 499 makes use of rideability indices, or RI values. Based on past experience, the RI-index provides a general means of evaluating the general condition of a pavement. Relationships between critical RI-values, traffic volumes, and pavement conditions are defined in Figure 12 (Burchett, 2001)

Rideability Index data was obtained from the Kentucky Transportation Cabinet's Pavement Management Branch. Data was available for the years 2001, 2002, and 2003. The RI has decreased each year as shown in Figure 13. The average RI for the section of roadway was 2.95 in 2001, 2.52 in 2002, and 2.21 in 2003 (Figure 14). The annual average daily traffic (AADT)

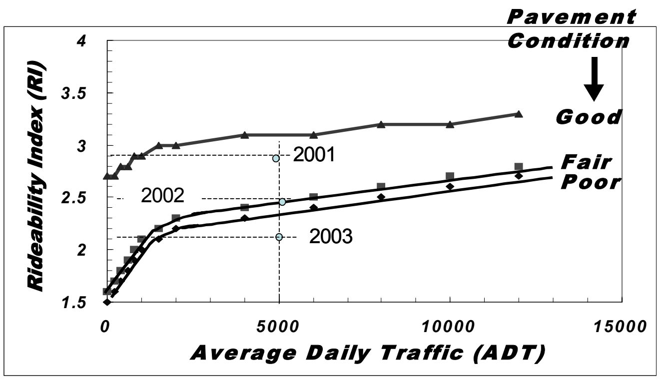


Figure 12. Rideability Index as a Function of the Average Annual Daily Traffic and Condition of Pavement

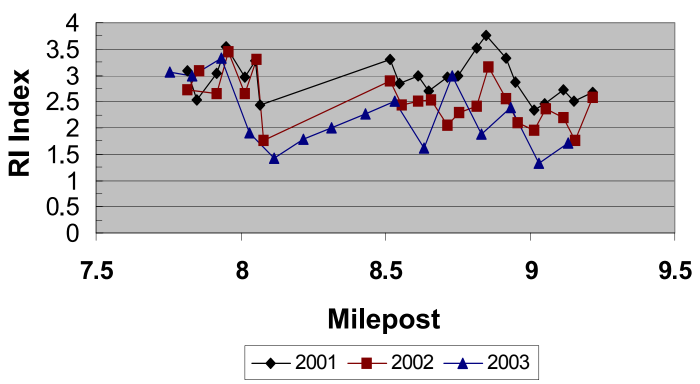


Figure 13. Rideability Index Data for the Roadway Section

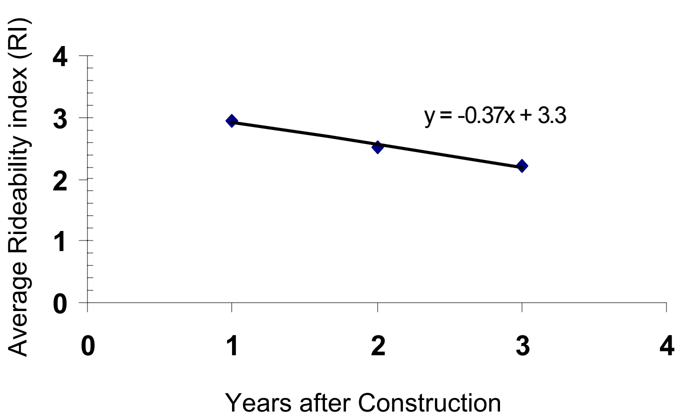


Figure 14. Rideability Index as a Function of Years after Construction

for the year 2003 was 5020 (the only value available). Based on the value of AADT and RI-values, the general pavement condition after one year of construction was between "good" and "fair." By 2002, the condition of the pavement had decreased to "fair." The pavement condition decreased more by 2003 to "Poor," as shown in Figure 12.

GEOCHEMICAL TESTS

Scanning Electron Microscope

Scanning electron microscope tests were performed by personnel of the University of Kentucky's Scanning Electron Microscope Facility on two standard penetration test samples each from the stabilized and non-stabilized subgrades. The most noticeable difference between the hydrated-lime stabilized subgrade samples and non-stabilized samples obtained directly below the stabilized layer was the presence of calcium (Ca) in the stabilized subgrade, as shown in Figure 15. This is expected because calcium is a principal component of hydrated lime, $Ca(OH)_2$. Small amounts of sulfur (S) and iron (Fe) were detected in samples from both layers. The presence of sulfur is significant because sulfates could form when the sulfur is oxidized. If the sulfate quantity is large enough, and calcium is present in a basic, high pH environment, gypsum and other calcium-sulfur based minerals such as ettringite, can form. These minerals form large crystals in the voids that are present in the soil structure and absorb water, which causes swelling. Iron and sulfur can form pyrite (FeS). The oxidation of pyrite has been a factor in the swelling in building subgrades, where crushed limestone has been placed between a concrete slab and fill material containing pyrite, such as New Albany and Chattanooga shale formations.

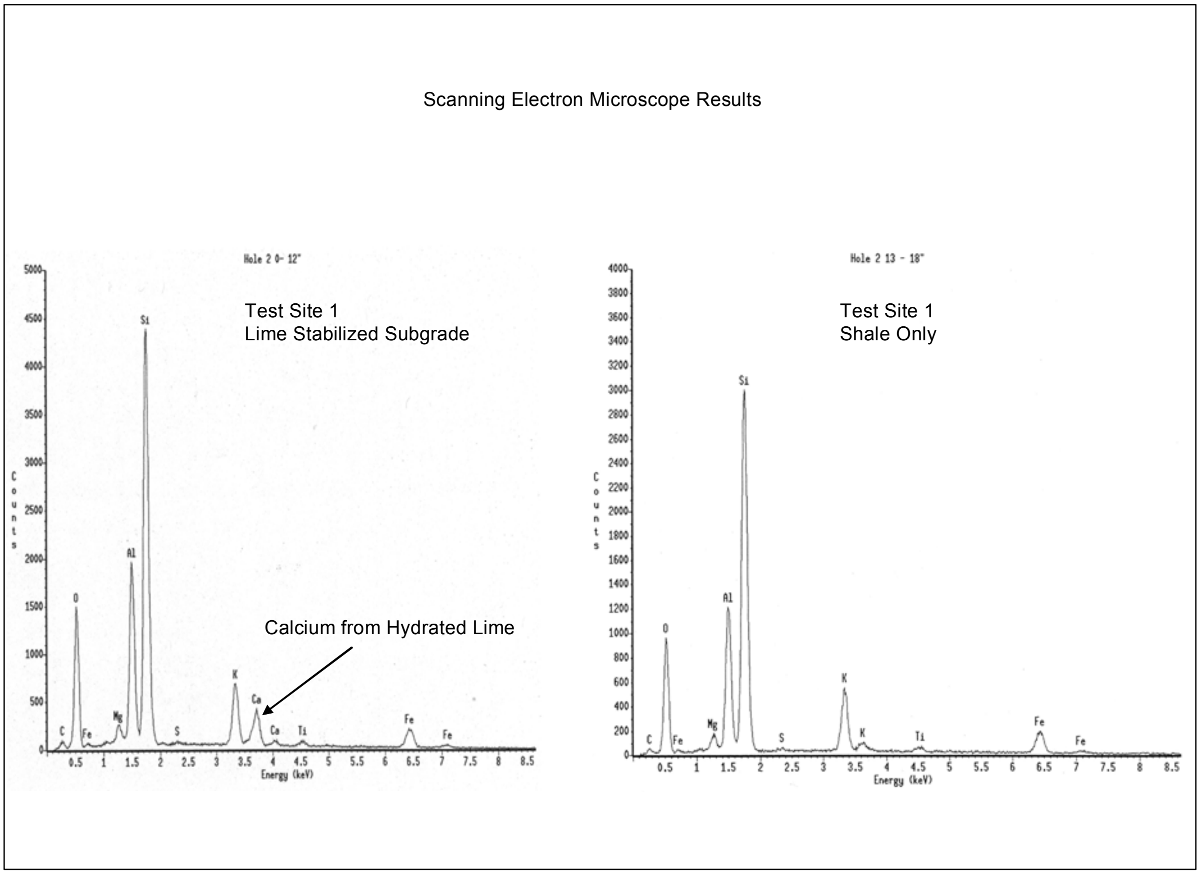


Figure 15. Results from Scanning Electron Microscope Tests

X-Ray Diffraction

X-Ray Diffraction tests were performed by the University of Kentucky's Center for Applied Energy Research on two standard penetration test samples each from the stabilized and non-stabilized subgrades. The diffraction patterns from these tests indicated that the major crystalline phases present are quartz, dolomite, and montmorillonite clay. No significant differences were observed in the hydrated-lime stabilized shale and the non-stabilized shale sample as shown by results in Figures 16 and 17**.** Gypsum, ettringite, and pyrite were not detected. Absence of calcium sulfate-type minerals (mainly gypsum and ettringite) indicates that no calcium sulfate reactions occurred in the subgrade and caused swelling. Pyrite was not detected. This finding rules out the possibility that pyrite oxidation occurred and contributed to pavement swelling.

Montmorillonite was detected. Montmorillonite is an aluminum silicate clay mineral that will absorb water and swell. Based on these results and swell tests, swelling of the compacted subgrade shale and intact shale below the stabilized subgrade is the major cause of pavement swelling.

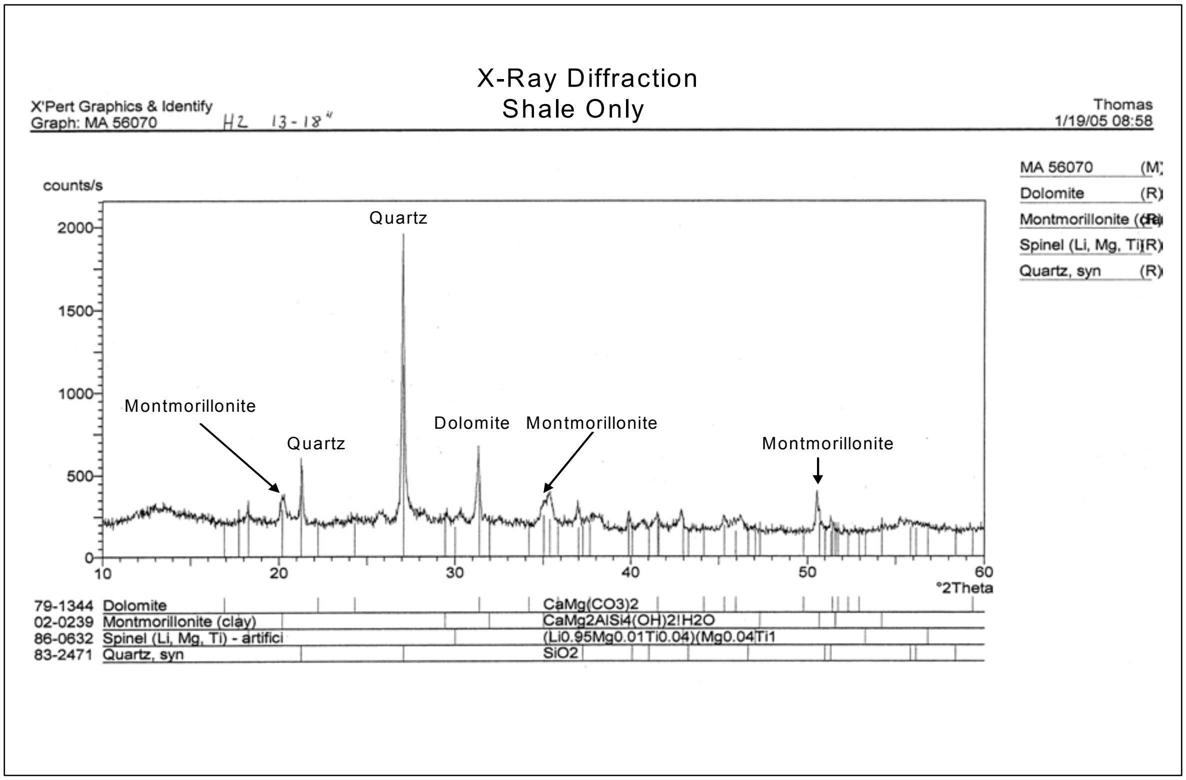


Figure. 16. Results from X-Ray Diffraction Tests, Below Lime Stabilized Layer.

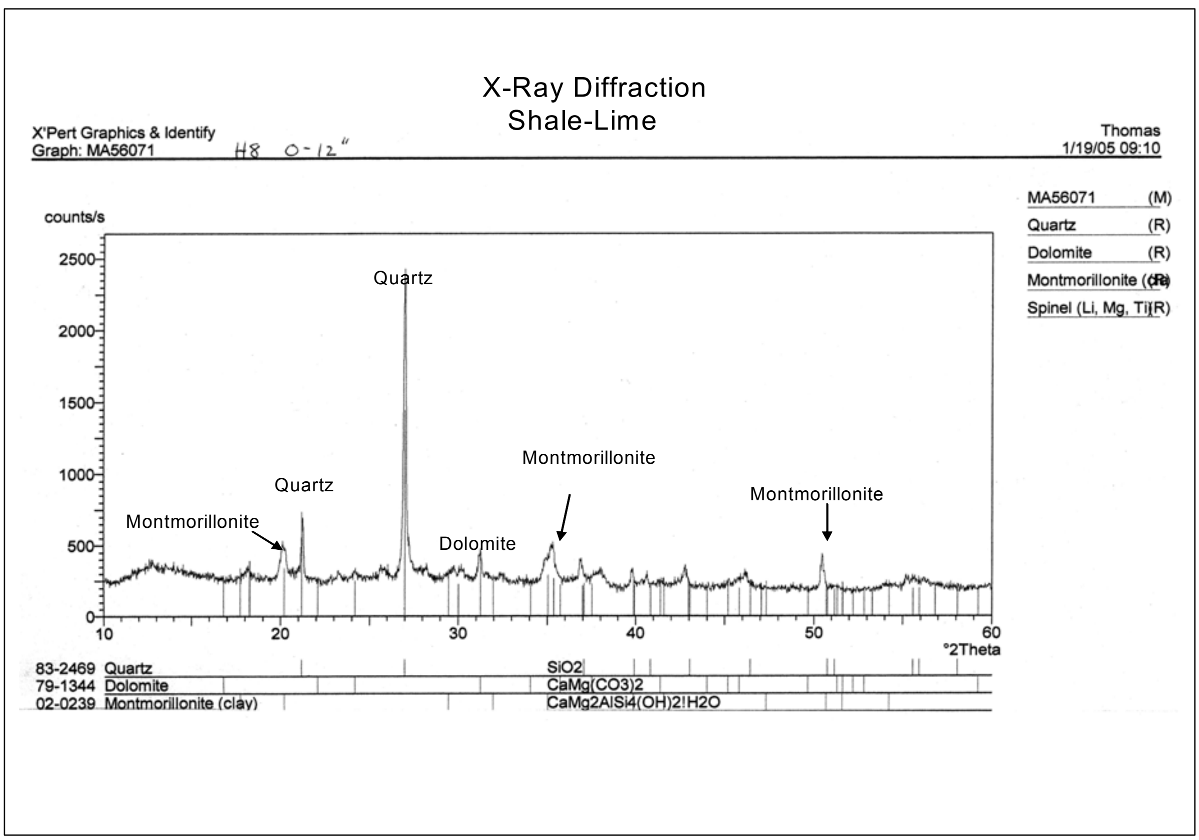


Figure 17. Results from X-Ray Diffraction Tests, Compacted Lime Stabilized Layer

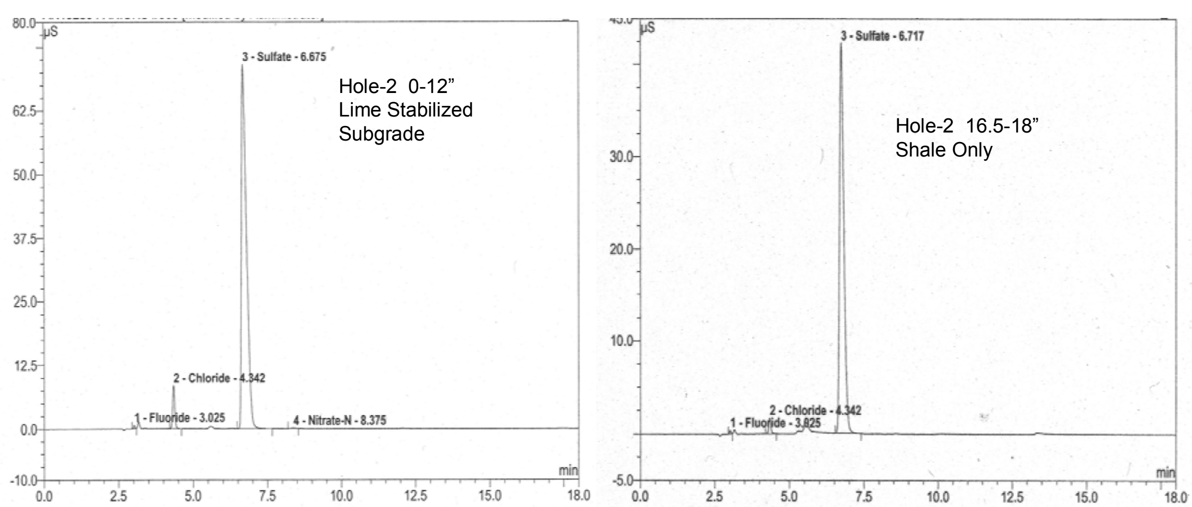
Sulfates

Analysis of a soil sample for sulfates by the University of Kentucky's Environmental Research Training Laboratory average sulfate levels of 667 parts per million (ppm) in the non stabilized shale and 1,319 in the stabilized shale. Sulfate levels in the DGA base were 20 ppm. Typical results from one test each on the hydrated-stabilized soil and on the non-stabilized shale are shown in Figure 15. The threshold amount of sulfates required to cause damaging reactions with calcium and form gypsum or ettringite is not known. Some research has shown that sulfate levels in soils from Texas, below 3,000 ppm, will not cause significant swelling in hydrated-lime stabilized soils (Harris, et al 2003). Based on that study, sufficient sulfate levels were not present.

pH

Laboratory pH tests were performed on samples of the hydrated-lime stabilized subgrade and on the shale only subgrade. The pH of the shale with hydrated-lime was 12.2. This range is acceptable for cementious chemical reactions to occur between the shale and hydrated-lime. The pH of the shale only was 7.5

Sulfates



No.	Ret.Time min	Peak Name	Amount ppm	Area µS*min	Type
1	3.03	Fluoride	1.8498	0.037	BMB*
2	4.34	Chloride	47.5353	0.683	BMB
3	6.68	Sulfate	1328.8076	[illegible]	BMB*
4	8.38	Nitrate-N	3.8935	0.020	BMB

Sulfates

No.	Ret.Time min	Peak Name	Amount ppm	Area µS*min	Type
1	3.03	Fluoride	0.9730	0.019	BMB*
2	4.34	Chloride	9.2682	0.133	BMB
3	6.72	Sulfate	676.8590	7.123	BMB*

Figure 18. Amount of Sulfates Detected in the Lime Stabilized and Shale Only Subgrades

CONCLUSIONS AND RECOMMENDATIONS

Excessive pavement swelling was due to compacted and in situ Crab Orchard Shale being exposed to moisture. X-ray diffraction tests detected montmorillonite in the clay shale. Montmorillonite is known to absorb available moisture and swell. The swell pressure exerted from the swelling clay located below the pavement and stabilized subgrade was greater than the overburden pressure from the asphalt, gravel base and stabilized subgrade combined. Lime stabilization reduced swelling of the compacted shale. Allowing compacted shale lime mixtures to cure, before being exposed to moisture sources, reduces swelling further.

No gypsum, ettringite, or other calcium sulfate based minerals were found in the hydrated lime stabilized subgrade. Sulfates were detected but may be too low for sulfate calcium reactions to occur and contribute to the swelling. Further research is needed to determine acceptable levels of sulfates.

Drainage ditches should be reconstructed at the central test site. The pavement humps will require periodic milling. Temporary patches will also have to be used. Periodic measurements of points placed on the pavement at different locations during this study may aid in establishing the pattern of swelling and provide some hint of the long-term swelling behavior of the compacted and intact Crab Orchard shale.

Further research is needed to establish better methods for constructing highways through areas where problematic clay shale, such as the Crab Orchard and New Providence formations are located.

ACKNOWLEDGEMENTS

This study is part of a research study examining the effects of saturated subgrades on pavement performance. The Kentucky Transportation Center and Federal Highway Administration provided funding. Bill Broyles, Geotechnical Branch Manager is Chairperson of the research Study Advisory Committee.

Tim Adams and Mike Rodgers, resident engineer and construction inspector, respectively, for the project provided plans, survey control points and construction information. Anthony Bowling, Branch Manager for Maintenance District 10, provided traffic control for field-testing. Larry Rice from the University of Kentucky' Scanning Electron Microscope Facility performed the SEM tests, John May, with the University of Kentucky's Environmental Research Training Laboratory, for performed total sulfates tests, Gerald Thomas and Bob Rathbone, with the University of Kentucky Center for Applied Energy Research performed and analyzed x-ray diffraction tests.

REFERENCES

Burchett, J. *"Pavement Management in Kentucky: An Overview in Year 2001,"* Pavement Management Branch of the Kentucky Transportation Cabinet, February 2001— private communication with Jim Burchett, former Branch Manager.

Harris, P.; Sebesta, S.; and Scullion, T. *"Hydrated Lime Stabilization of Sulfate-Bearing Soils in Texas,"* University of Texas, Texas Transportation Institute, July 2003.

Molen, D. Memorandum *Geotechnical Engineering Report Estill County, KY 52 – KY 89 Connector (Irvine By-Pass)*, Kentucky Transportation Cabinet, Division of Materials, Geotechnical Branch, May 1997.

Hunsucker, D. Q.; Hopkins, T.C.; and Graves, R. C. *"Construction and Performance of Highway Soil Subgrades Modified with Atmospheric Fluidized Bed Combustion Residue and Multicone Kiln Dust,"* KTC-93-4, January 1993.

Hopkins, T.C.; *"Bearing Capacity Analysis of Pavements,"* KTC-91-8, February 1991.

Hopkins, T. C.; Girdler, H. F.; and Yoder, S. M.; "*Stability of a Side-Hill Embankment,"* I 64, Lexington - Catlettsburg Road April 1973.

Hopkins, T.C. Beckham, T.L.; and Hunsucker, D. Q. *"Modification of Highway Soil Subgrades,"* University of Kentucky, Kentucky Transportation Center, June 1994.