Research Report
KTC-97-20

Stabilization of an Airport Subgrade using Hydrated Lime and Fly Ash

by

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INTRODUCTION

A 457- m (1,500-ft) runway pavement extension is planned for the Georgetown-Scott County Airport (Marshall Field). The clay subgrade of the existing paved runway was stabilized with six percent (dry weight) hydrated lime. A request was made by the Kentucky Transportation Cabinet, Division of Aeronautics, to determine the feasibility of replacing a percentage of the hydrated lime stabilizer with fly ash for the extended runway subgrade. Kentucky Highway Investigative Task No. 27 was issued by the Transportation Cabinet to fund a laboratory study to determine the effects of partially replacing lime with Type F fly ash (FA). Using fly ash to replace lime could potentially, reduce stabilization cost and provide a means of using fly ash as a byproduct in lieu of landfill disposal. The subgrade extension was previously constructed to final grade with clay soils. A thin layer of topsoil and grass currently covers the subgrade. Stabilization of the extended runway is planned during pavement construction.

BACKGROUND

The Kentucky Transportation Cabinet has used hydrated, calcium hydroxide - $Ca(OH)_2$, or quick lime, calcium oxide - CaO since 1987 to stabilize clay subgrades when the California Bearing Ratio (CBR) value is six or less. This recommendation was made by the Geotechnology Section of the University of Kentucky Transportation Center as a result of various research studies (1,2). The addition of lime (typically five percent of dry weight) improves the bearing capacity and compressive strength of clay subgrades. Lime reacts with clay particles and improves engineering properties of the clay.

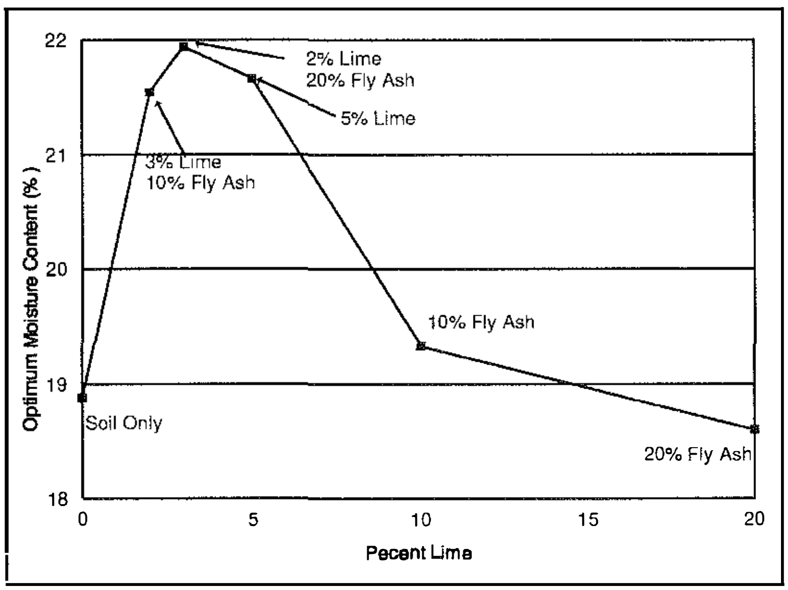

Figure 1. Changes in optimum moisture content with varying percentages of lime and fly ash.

Fly ash, combined with hydrated lime or Portland cement, has been used in stabilized subgrades and granular base construction in other states. Hydrated lime and fly ash are used in Kentucky to construct stabilized granular bases.

INITIAL TESTING

A bulk sample of the clayey subgrade was obtained near centerline, approximately 39 m (100 feet) from the edge of the existing pavement. Basic laboratory tests, such as grain size, liquid and plastic limits, and specific gravity were performed to determine soil classification. Other tests, which

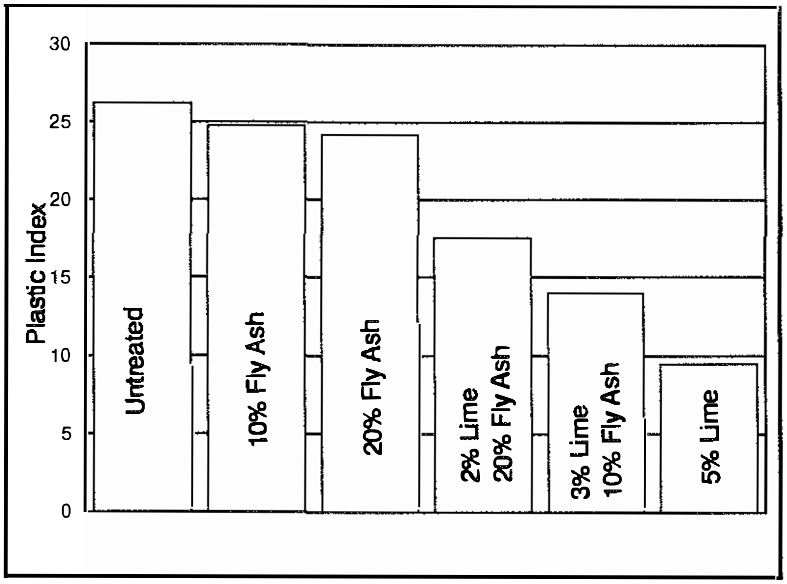

Figure 3. Changes in plasticity index when various percentages of lime and fly ash are used as chemical additives.

included moisture-density, bearing ratio, and unconfined compressive strength, were performed to determine strength properties of compacted specimens of the soil.

Moisture-density relations and classification (liquid limit, plastic limit, particle size, and specific gravity) tests were also performed on four different series of clayey samples which contained various combinations of hydrated lime and Type F fly ash. The first series consisted of 5 percent hydrated lime and clay. The second series consisted of 3 percent hydrated lime, 10 percent fly ash, and clay. The third series consisted of 2 percent lime, 20 fly ash, and clay. Finally, the fourth and fifth series consisted of 10 percent fly ash and clay, and 20 percent fly ash and clay, respectively. Results of classification tests are presented in Table 1 and Appendix A. Results of moisture-density tests are shown in Table 2 and Appendix B.

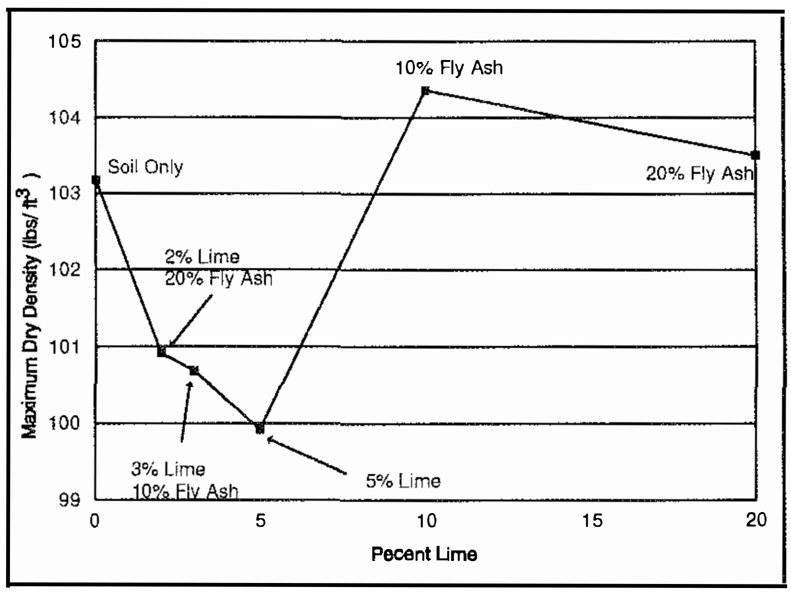

Figure 2. Variations of maximum dry density with varying percentages of lime and fly ash.

Maximum dry density obtained from moisture-density tests usually decreases as the amount of hydrated lime added increases. Conversely, the optimum moisture content increases. The optimum moisture content increased when lime and fly ash were both added. However, optimum moisture content decreased when only fly ash was added, as seen in Figure 1. Maximum dry density decreased with the addition of lime and fly ash. Dry density increased when 10 percent of fly ash was added and decreased when 20 percent of fly ash was added, as shown in Figure 2.

Table 1. Results of moisture-density tests for varying percentage of lime and lime fly ash mixtures.

Sample	Maximum Dry Density kg/m^3 (lbs/ ft^3)	Optimum Moisture Content (%)
Soil	1652 (103.17)	18.88
5% Lime	1600 (99.92)	21.66
3% Lime 10% Fly Ash	1616 (100.91)	21.54
2% Lime 20% Fly Ash	1612 (100.67)	21.94
10% Fly Ash	1671 (104.36)	19.33
20% Fly Ash	1658 (103.50)	18.60

Changes in Soil Properties

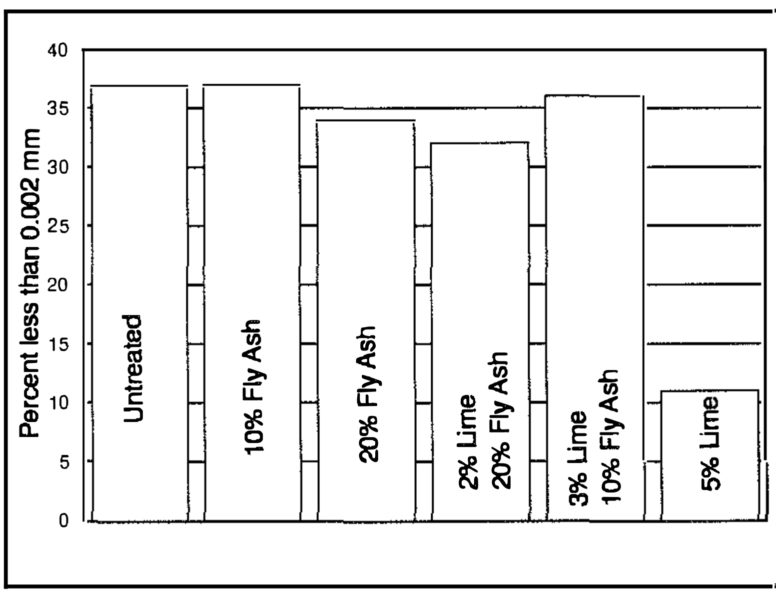

Figure 4. Changes in percent less than 0.002 mm with varying percentages of lime and fly ash.

The plasticity index of the subgrade soil and the percentage of the sample less than the 0.002-mm particle size decreases as the percent of hydrated lime added increases. The reaction between the lime and clay changes the properties of the soil. The soil initially was classified as a CH or "fat clay" by the Unified Classification System and A-7-6 with a group index (GI) of 20 by the AASHTO classification system. A GI of 20 or greater indicates a "very poor" subgrade material where a GI of zero indicates a "good" subgrade soil (2). The addition of 5 percent by dry weight of hydrated lime to the clay changed the classification from CH and A-7-6 (20) to SM and A-4 (0), respectively-- a silty sandl. Mixtures containing 2 percent lime and 20 percent fly ash changed classifications to CL, lean clay, and A-7-6 (16), respectively. When 3 percent lime and 10 percent fly ash were mixed with the clay, the classification changed to CL and A-7-5 (15), respectively. The addition of 10 and 20 percent fly ash to the clay changed classifications to CL, and A-7-6 (23). Changes in classification are due to the bonding of clay particles which is a result of chemical reactions between clay minerals and lime.

The clay particles are cemented together to form larger silt-size to sand-size particles. Changes in plasticity index and percent finer than 0.002 mm particle sizes are shown in Table 2 and Figures 3 and 4.

Table 2. Changes in classification properties with varying percentage of lime, lime-fly ash, and fly ash mixtures.

Sample	Limits			Sp. Gr.	Percent Passing				Classification	
	LL	PL	PI		No.4 4.75 mm	No.10 2.0 mm	No. 200 .075 mm	.002 mm	UCS	AASHTO
Soil	52	26	26	2.82	89	85	76	34	CH	A-7-6 (20)
5% Lime	18	15	3	2.78	100	100	40	11	SM	A-4 (0)
3% Lime 10% F A	48	34	14	2.73	100	100	88	36	CL	A-7-5 (15)
2% Lime 20% FA	43	25	18	2.71	100	100	84	31	CL	A-7-6 (16)
10% FA	47	23	24	2.74	100	100	88	37	CL	A-7-6 (23)
20%FA	46	23	23	2.72	100	100	88	37	CL	A-7-6 (23)

UNCONFINED COMPRESSIVE STRENGTH TESTS

A series of unconfined compressive strength tests was performed on specimens mixed with different percentages of hydrated lime. The percentages ranged from one to ten. The samples were recompacted near ninety five percent of standard dry density and optimum moisture content and aged for seven days at room temperature. This procedure, developed at the Kentucky Transportation Center (1), and used by Kentucky Transportation Cabinet, Division of Materials, Geotechnical Branch, to determine

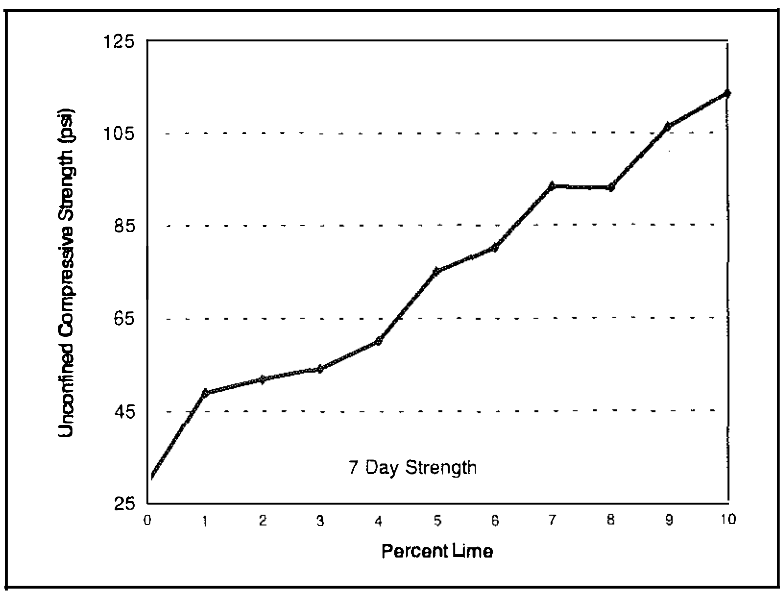

Figure 5. Increase in unconfined compressive strength with increasing percent hydrated lime additive.

the optimum percentage of chemical stabilizer for highway subgrades. In using this procedure, several soil samples are recompacted at different percentages of lime. The optimum percentage is a point where there is no significant increase in unconfined compressive strength as the percentage of hydrated lime increases. The Transportation Cabinet uses an accelerated curing time (two days at 38° C or 100 °F). As seen in Figure 5, the unconfined compressive strength increases as the percentage of hydrated lime increases for this sample. Generally, an optimum strength is usually reached for many clay soils containing 5 to 6 percent of hydrated lime. However, for this particular soil the unconfined compressive strength continued to increase up to 10 percent lime. No well-defined optimum percentage of lime could be established from the results. In this particular case, the strength at five percent hydrated lime would still be very substantial to withstand traffic loadings during and after construction.

A second series of unconfined compressive strength tests were performed on lime-fly ash-soil samples recompacted near 95 percent of standard dry density and optimum moisture content. One series of samples contained 3 percent hydrated lime and 10 percent (dry weight) of fly ash. The third series contained 2 percent lime and 20 percent fly ash. The samples were recompacted and sealed in plastic bags. They were aged for different times at room temperature before testing. Strength gains were observed for both series of samples with increasing curing time as shown in Figure 4. At a curing time of 14 days, and room temperature, strength gains of specimens containing 3 percent of hydrated lime and 10 percent of fly ash were larger than the strengths of specimens containing 2 percent of hydrated lime and 20 percent of fly ash. In the former case, the unconfined compressive strength was 621 kPa (900 psi), while unconfined compressive strength in the latter case was 518 kPa (75 psi). A minimum unconfined compressive strength of 2,769 kPa (400 psi) is the criterion established in the American Society for Testing Materials (ASTM) C 593 (3) under accelerated curing conditions. According to ASTM C 593, an approximation of the 28-day strength may be obtained by curing specimens at 100° F (38° C), for seven days. However, this requirement has been reduced to as low as 690 kPa (100 psi) for subbase conditions (3). Unconfined compressive strength of the soil without additive, recompacted near 95 five percent of standard maximum dry density and near optimum moisture content was about 200 kPa psi (29 psi).

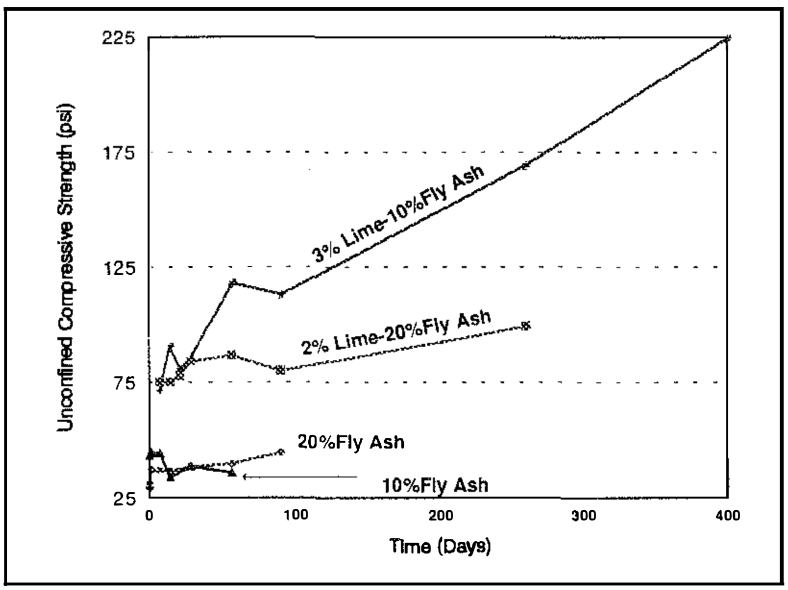

Figure 6. Unconfined compressive strength versus curing time for varying percentages of lim-fly ash mixtures.

BEARING RATIO TESTS

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

- ❍Clay only
- ❍Clay and 5% hydrated lime
- ❍Clay, 2% hydrated lime, and 20% fly ash
- ❍Clay, 3% hydrated lime, and 20% fly ash
- ❍Clay and 10 % fly ash
- ❍Clay and 20 % fly ash

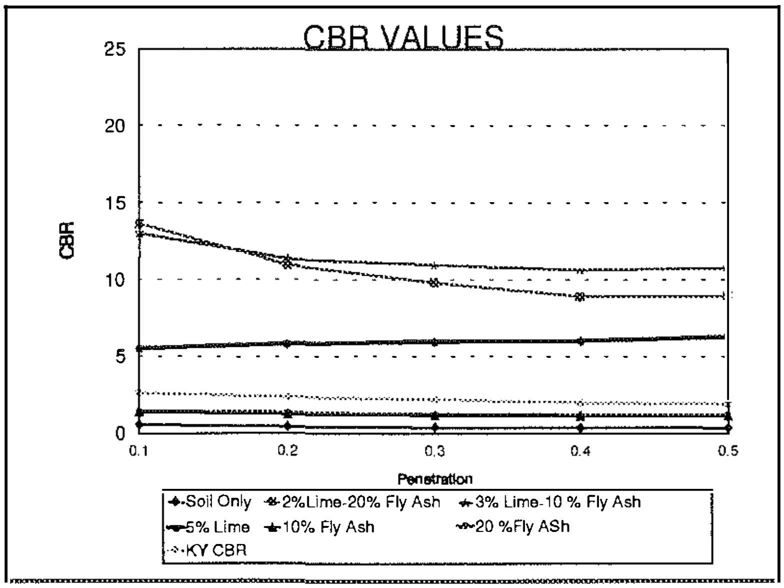

Figure 7. CBR Values of soil and soil-lime-fly ash mixtures.

A CBR test was also performed on the soil only following the procedure used by the Kentucky Transportation Cabinet (KM 508). Generally, CBR values obtained from KM 508 for fine-grained soils are higher than those obtained from ASTM D 1883 or AASHTO T 193 methods due to compaction differences (4). Usually, the dry density obtained when the procedures of KM 508 are followed are larger than the dry density obtained from AASHTO or ASTM methods. The value of the AASHTO CBR was 0.5 at 0.1 in. (2.5 mm) penetration, while the CBR value obtained from the Kentucky Method was 2.0.Two series of AASHTO CBR tests were performed. The first series was performed strictly following AASHTO procedures. The samples were compacted to the desired density and moisture content and allowed to soak in water for a period of 96 hours (4 days). The second series was compacted and allowed to soak in water for an extended period of time (56- 58 days). The latter series of tests were performed for two reasons:

1. to determine any long-term swelling that may occur. (Past experience has shown that some byproducts generated from coal-fired electric generating plants, contain lime and sulfur have compounds which produce swell reactions when exposed to water for extended periods of time -- (more than 100 hours), and

2. to determine if extended exposure to moisture had any effects on bearing capacity.

CBR values for soil-lime-fly ash specimens ranged from about 16 to 24 for specimens submerged in water for extended periods of time (56 - 58 days). CBR values of soil-lime-fly ash specimens soaked for the standard 96, hour period, were lower, ranging from approximately 8 to 14. Apparently, cementing reactions between the hydrated lime and clay increased when the soil-lime mixtures where in the presence of water. No excessive swell was observed. Results of CBR tests are shown in Figures 7 and 8.

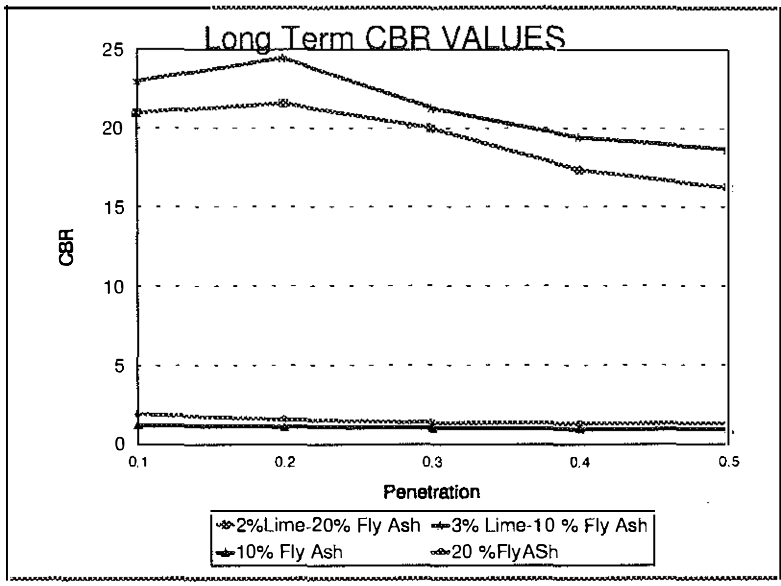

Figure 8. Long-term CBR values of soil-lime-fly ash mixtures.

SOIL-FLY ASH TESTING

Test results showed that the lime and fly ash additives increased the bearing capacity and unconfined compressive strengths of the soil. It is well known that hydrated or quick lime improves strength and bearing ratio of clayey soils. Thc Kentucky Transportation Cabinet stabilizes clay subgrades when the CBR values are 6 or less. To determine if strength gains occur when fly ash is added to the clay, a series of tests were performed on recompacted soil-fly ash mixtures. Additional material was obtained from the same subgradc location. Moisture-density tests were performed on the airport soil using 10 and 20 percent (dry weight) fly ash. A series of unconfined compressive strength tests and CBR tests were performed. As shown in Figures 4 and 6, respectively, increases in unconfined compressive strength or bearing capacity did not occur when only fly ash was added to the clay. For mixtures of 2 percent lime-20 percent fly ash-clay and 3 percent lime-10 percentfly ash-clay, cured for 14 days, strengths of 517.5 and 621 kPa, (75 and 90 psi) respectively were obtained.

The fly ash, Type F, was supplied by the Kentucky Utilities Company. The sample was obtained from Kentucky Utilities Ghent Generating Station. A chemical analysis supplied with the sample indicated that only 0.5 percent Calcium Oxide, CaO, was present in the sample. The failure of the fly ash to improve the engineering properties of the clay when no other additives were used can be attributed to the low percentage of CaO in the fly ash. Chemical and physical analyzes, shown in Table 3, were performed by JTM Industries, Inc., Winfield, West Virginia.

CONCLUSIONS

The soil-lime-fly ash mixtures (2 percent lime- 20 percent fly ash and 3 percent lime-10 percent fly ash) did improve the subgrade properties. Increases in unconfined compressive strength and bearing

Table 3. Chemical and Physical Analyzes of Fly Ash.

Chemical Analysis	Percent	ASTM C 618 Specifications
Silicon Dioxide (SiO_2)	59.90	
Aluminum Oxide (Al_2O_3)	30.20	
Iron Oxide (Fe_2O_3)	3.50	
Sum of SiO_2 ,Al_2O_3 ,Fe_2O_3	93.60	70.0 Minimum
Magnesium Oxide (MgO)	0.80	
Sulfur Trioxide (SO_3)	0.2	5.0 Maximum
Moisture Content	0.12	3.0 Maximum
Loss on Ignition	1.77	6.0 Maximum
Avaliable Alkalies as Na_2O	0.55	1.5 Maximum*
Calcium Oxide (CaO)	0.5	
Physical Analysis		
Fineness (Retained on 325 Sieve)	19.30	34 Maximum
Water Requirement, % Control	97.0	105 Maximum
Specific Gravity	2.16	
Autoclave Expansion	0.05	0.8 Maximum
Pozzolanic activity with Portland cement, 28 days	80.00	75 Minimum

* Only when required by the customer

capacity were observed with lime and lime-fly ash additives. Testing with only fly ash did not improve strength or bearing capacity. This result indicated strength gains were due to reactions between the soil and lime. Sufficient strength, about 517.5 and 621 kPa (75 and 90 psi), at 14 days curing time for the 2 percent lime-20 percent fly ash and 3 percent lime-10 percent fly ash, respectively, and bearing capacity gains (CBR values between 9 and 13 for standard saturation times and 16-24 for long term soaking periods) were obtained from the mixtures to construct an effective subgrade.

RECOMMENDATIONS

The subgrade can be improved by stabilizing with soil-fly ash mixtures. Improvements in strength and bearing capacity are from soil lime reactions. The benefit of using fly ash would be an alternative to landfill disposal. A minimum of 14 days curing time should be used if the soil. A blend of soil lime fly ash mixtures may be required to produce a minimum of 690 kPa (100 psi) unconfined compressive strength. The Kentucky Transportation Cabinet requires a minimum seven day cure time when highway subgrades are stabilized with hydrated or quick lime. A bearing capacity analysis should be performed using available subgrade strengths as part of the pavement design.

Future research effort should concentrate on using Type C fly ash as a subgrade stabilizing agent with lime or Portland cement depending upon specific soil properties. Type C fly ash typically contains about 24 percent calcium oxide (CaO) (6).

REFERENCES

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3 ***"Standard Specification for Fly Ash and Other Pozzolans for use with Lime,"*** ASTM C 593-95, ASTM Annual Book of Standards, Vol 04.01, ASTM, West Conshohocken, Pennsylvania, 1996.

4. Meyers, J. F.; Pichumani, R.; and Kapplers, B. S.; ***"Fly Ash as a Highway Construction Material,"*** U. S. Department of Transportation, Federal Highway Administration, Washington, D. C., Report No. 76-16, June 1976.

5. Beckham, T. L., and Allen, D. A.; ***"Correlation of ASTM and Kentucky CBR Methods for Fayette County,"*** University of Kentucky, Kentucky Transportation Center, Lexington, Kentucky. Report No. KTC-90-17, August 1990.

6. Boles, W. F.; ***"Fly Ash Facts for Highway Engineers,"*** U. S. Department of Transportation, Federal Highway Administration, Washington, D. C., Report No. FHWA-DP-59-8, July 1986.

APPENDIX A
Classification Data and Grain Size Curves

LABORATORY RECORD OF SOIL TEST DATA

SAMPLE ID	LL	PL	PI	SPGR	AASHTO	GI	USC
Soil	52.0	26.0	26.0	2.82	A-7-6	(20)	CH

MECHANICAL SIEVE ANALYSIS

SIEVE SIZE	WEIGHT RETAINED	TOTAL PERCENT PASSING
2 IN	0.00	100.00
1 1/2 IN	537.30	97.67
1 IN	279.24	96.46
3/4 IN	635.10	93.70
1/2 IN	568.67	91.24
3/8 IN	214.81	90.31
NO. 4	246.39	89.24
NO. 10	909.33	85.29

HYDROMETER SIEVE ANALYSIS

SIEVE SIZE	WEIGHT RETAINED	TOTAL PERCENT PASSING
NO. 20	1.44	83.26
NO. 40	1.68	80.89
NO. 60	1.31	79.04
NO. 200	2.07	76.11

HYDROMETER ANALYSIS

TIME (MIN)	TEMP °F	HYD READING	PERCENT FINER	PARTICLE DIAMETER-MM
1.00	62.00	55.00	65.10	0.03611
2.00	62.00	53.50	63.06	0.02597
5.00	62.00	51.00	59.65	0.01688
15.00	63.00	47.00	54.36	0.01008
32.50	63.50	44.00	50.27	0.00704
66.00	65.00	40.00	45.14	0.00505
247.00	68.00	35.00	38.82	0.00266
1440.00	70.00	30.00	32.33	0.00113

LABORATORY RECORD OF SOIL TEST DATA

SAMPLE ID	LL	PL	PI	SPGR	AASHTO	GI	USC
5% Lime	18.0	15.0	3.0	2.78	A-4	(0)	SM

MECHANICAL SIEVE ANALYSIS

SIEVE SIZE	WEIGHT RETAINED	TOTAL PERCENT PASSING
NO. 4	0.00	100.00
NO. 10	0.00	100.00

HYDROMETER SIEVE ANALYSIS

SIEVE SIZE	WEIGHT RETAINED	TOTAL PERCENT PASSING
NO. 20	16.72	72.64
NO. 40	15.09	47.95
NO. 60	3.43	42.34
NO. 200	1.38	40.09

HYDROMETER ANALYSIS

TIME (MIN)	TEMP °F	HYD READING	PERCENT FINER	PARTICLE DIAMETER-MM
1.00	68.00	25.50	30.22	0.04569
2.00	68.00	24.00	27.83	0.03264
5.00	68.00	22.50	25.44	0.02085
15.00	68.50	20.50	22.25	0.01219
37.00	69.00	18.00	18.46	0.00783
60.00	70.00	17.00	17.06	0.00615
247.00	72.00	14.00	12.68	0.00304
1453.00	68.50	12.50	9.50	0.00130

LABORATORY RECORD OF SOIL TEST DATA

SAMPLE ID	LL	PL	PI	SPGR	AASHTO	GI	USC
3% Lime 10% Fly Ash	48.0	34.0	14.0	2.70	A-7-5	(15)	CL

MECHANICAL SIEVE ANALYSIS

SIEVE SIZE	WEIGHT RETAINED	TOTAL PERCENT PASSING
NO. 4	0.00	100.00
NO. 10	0.00	100.00

HYDROMETER SIEVE ANALYSIS

SIEVE SIZE	WEIGHT RETAINED	TOTAL PERCENT PASSING
NO. 20	3.72	94.18
NO. 40	1.29	92.16
NO. 60	.86	90.82
NO. 200	1.94	87.79

HYDROMETER ANALYSIS

TIME (MIN)	TEMP °F	HYD READING	PERCENT FINER	PARTICLE DIAMETER-MM
1.00	68.50	58.00	79.68	0.03457
2.00	68.50	56.00	76.58	0.02504
5.00	68.50	53.00	71.94	0.01639
15.00	69.00	47.50	63.61	0.00995
30.00	69.50	44.00	58.19	0.00727
60.00	70.00	40.50	52.96	0.00527
304.00	70.50	31.50	39.02	0.00252
1465.00	73.00	26.00	31.16	0.00117

LABORATORY RECORD OF SOIL TEST DATA

SAMPLE ID	LL	PL	PI	SPGR	AASHTO	GI	USC
2% Lime 20% Fly Ash	43.0	25.0	18.0	2.71	A-7-6	(16)	CL

MECHANICAL SIEVE ANALYSIS

SIEVE SIZE	WEIGHT RETAINED	TOTAL PERCENT PASSING
NO. 4	0.00	100.00
NO. 10	0.00	100.00

HYDROMETER SIEVE ANALYSIS

SIEVE SIZE	WEIGHT RETAINED	TOTAL PERCENT PASSING
NO. 20	3.82	94.20
NO. 40	1.96	91.23
NO. 60	1.26	89.32
NO. 200	3.27	84.35

HYDROMETER ANALYSIS

TIME (MIN)	TEMP °F	HYD READING	PERCENT FINER	PARTICLE DIAMETER-MM
1.00	68.50	54.00	71.17	0.03614
2.00	68.50	52.00	68.17	0.02612
5.00	68.50	48.00	62.17	0.01722
15.00	69.00	43.00	54.85	0.01035
30.00	69.50	39.50	49.61	0.00755
60.00	70.00	36.50	45.29	0.00543
249.00	70.50	30.50	36.29	0.00279
1416.00	73.00	22.50	24.93	0.00121

LABORATORY RECORD OF SOIL TEST DATA

SAMPLE ID	LL	PL	PI	SPGR	AASHTO	GI	USC
10 % Fly Ash	47.0	23.0	24.0	2.74	A-7-6	(23)	CL

MECHANICAL SIEVE ANALYSIS

SIEVE SIZE	WEIGHT RETAINED	TOTAL PERCENT PASSINGO
NO. 4	0.00	100.00
NO. 10	0.00	100.00

HYDROMETER SIEVE ANALYSIS

SIEVE SIZE	WEIGHT RETAINED	TOTAL PERCENT PASSING
NO. 20	1.84	97.41
NO. 40	2.10	94.45
NO. 60	1.44	92.42
NO. 200	2.94	88.28

HYDROMETER ANALYSIS

TIME (MIN)	TEMP °F	HYD READING	PERCENT FINER	PARTICLE DIAMETER-MM
1.00	67.50	62.50	77.24	0.03243
2.00	67.50	60.00	73.78	0.02372
5.00	68.00	56.00	68.42	0.01566
15.00	68.00	51.00	61.50	0.00956
30.00	69.00	47.00	56.14	0.00699
60.00	70.50	43.00	50.77	0.00510
250.00	72.00	35.50	40.75	0.00263
1440.00	73.50	29.00	31.99	0.00114

LABORATORY RECORD OF SOIL TEST DATA

SAMPLE ID	LL	PL	PI	SPGR	AASHTO	GI	USC
20 % Fly Ash	47.0	23.0	24.0	2.72	A-7-6	(23)	CL

MECHANICAL SIEVE ANALYSIS

SIEVE SIZE	WEIGHT RETAINED	TOTAL PERCENT PASSING
NO. 4	0.00	100.00
NO. 10	0.00	100.00

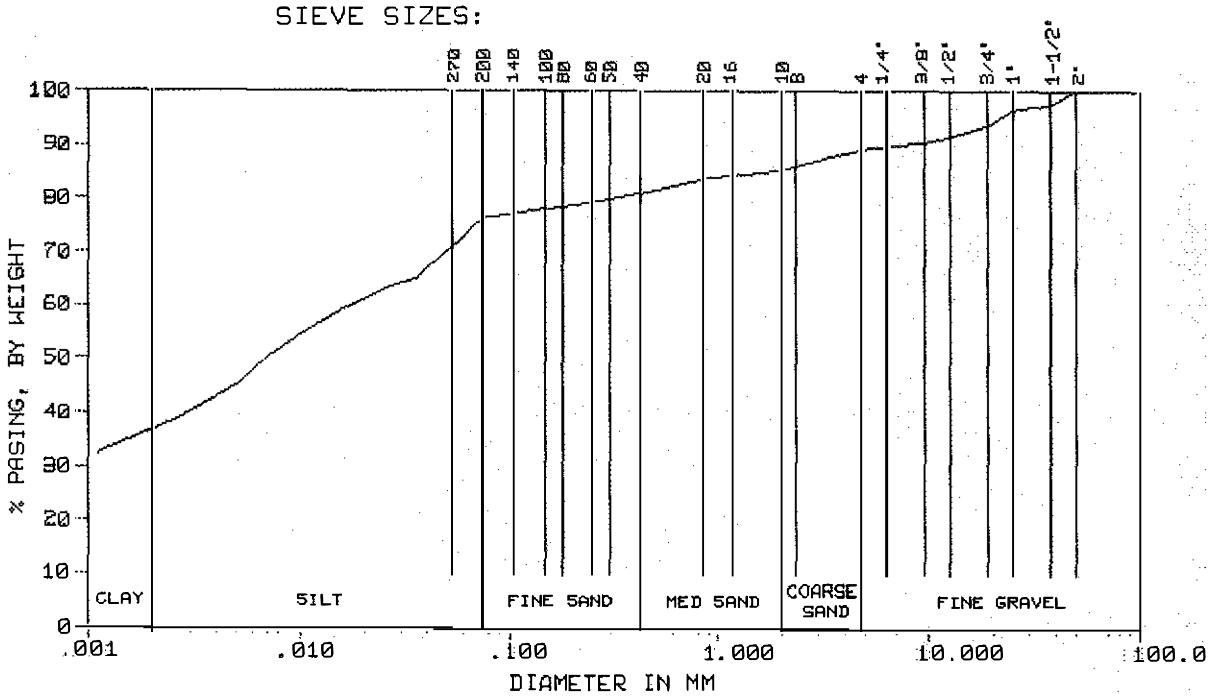
HYDROMETER SIEVE ANALYSIS

SIEVE SIZE	WEIGHT RETAINED	TOTAL PERCENT PASSING
NO. 20	1.84	97.56
NO. 40	2.04	94.85
NO. 60	1.47	92.90
NO. 200	3.56	88.17

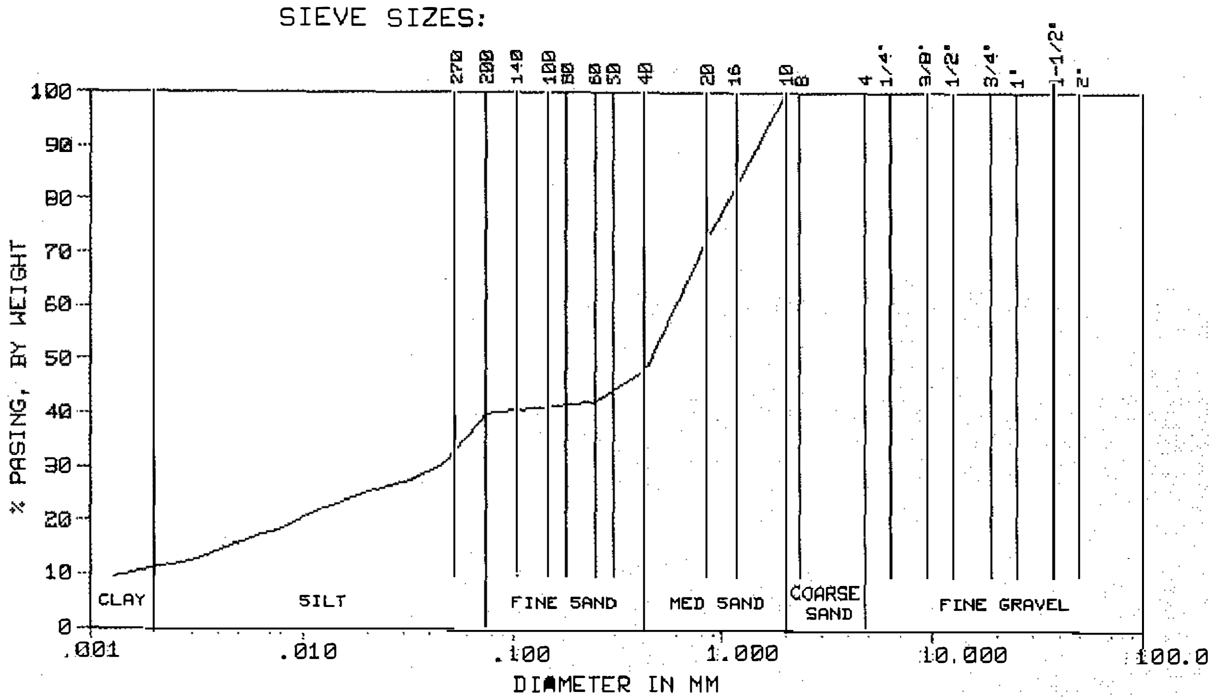
HYDROMETER ANALYSIS

TIME (MIN)	TEMP °F	HYD READING	PERCENT FINER	PARTICLE DIAMETER-MM
1.00	66.00	62.50	72.96	0.03285
2.00	66.00	60.00	69.69	0.02402
5.00	66.00	58.00	67.07	0.01558
15.00	67.00	54.00	61.99	0.00937
30.00	67.50	50.00	56.75	0.00692
60.00	69.00	45.00	50.52	0.00507
250.00	74.00	34.00	37.06	0.00264
1440.00	71.50	29.00	29.83	0.00116

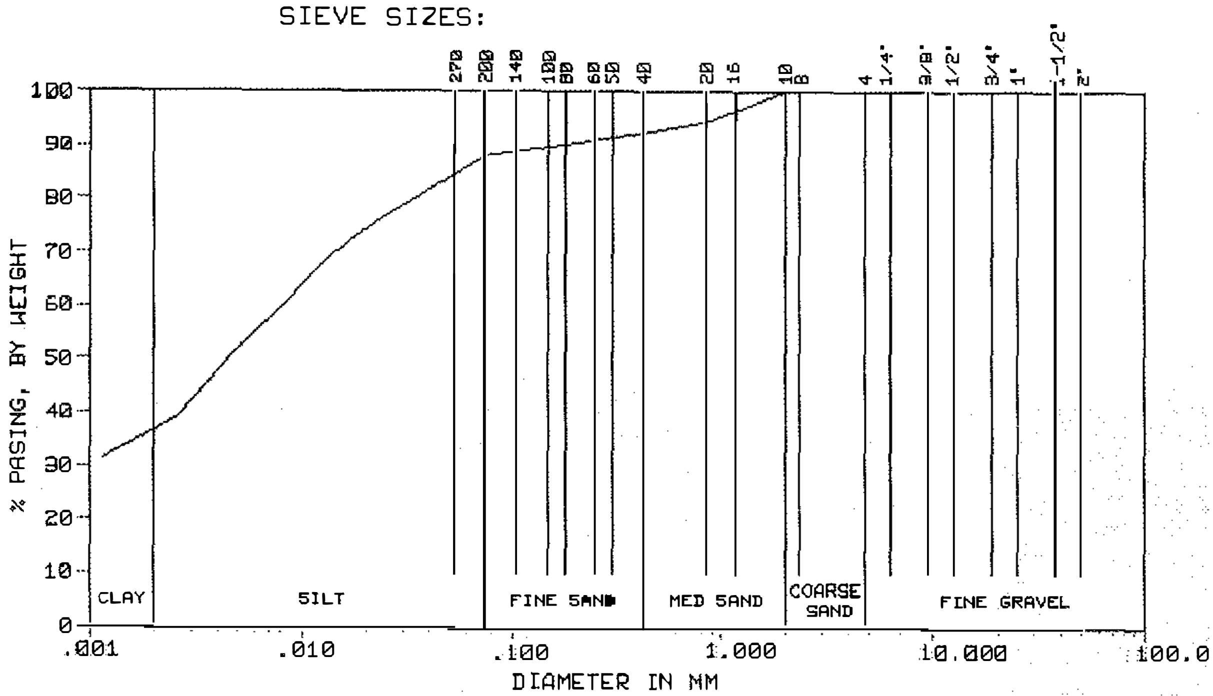
Soil

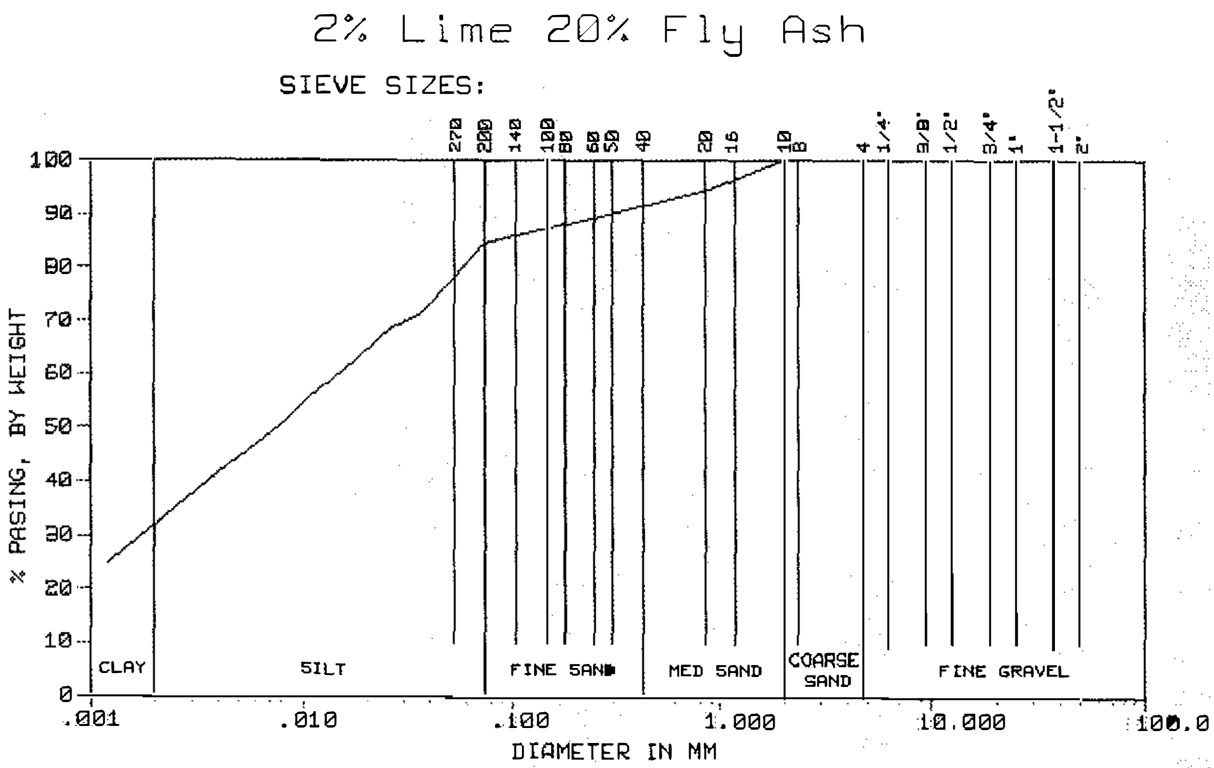

SIEVE SIZES:
270
200
140
100
80
60
50
40
20
16
10
8
4
1/4"
3/8"
1/2"
3/4"
1"
1-1/2"
2"
% PASING, BY WEIGHT
100
90
80
70
60
50
40
30
20
10
0
CLAY
SILT
FINE SAND
MED SAND
COARSE SAND
FINE GRAVEL
.001
.010
.100
1.000
10.000
100.0
DIAMETER IN MM

5% LIME

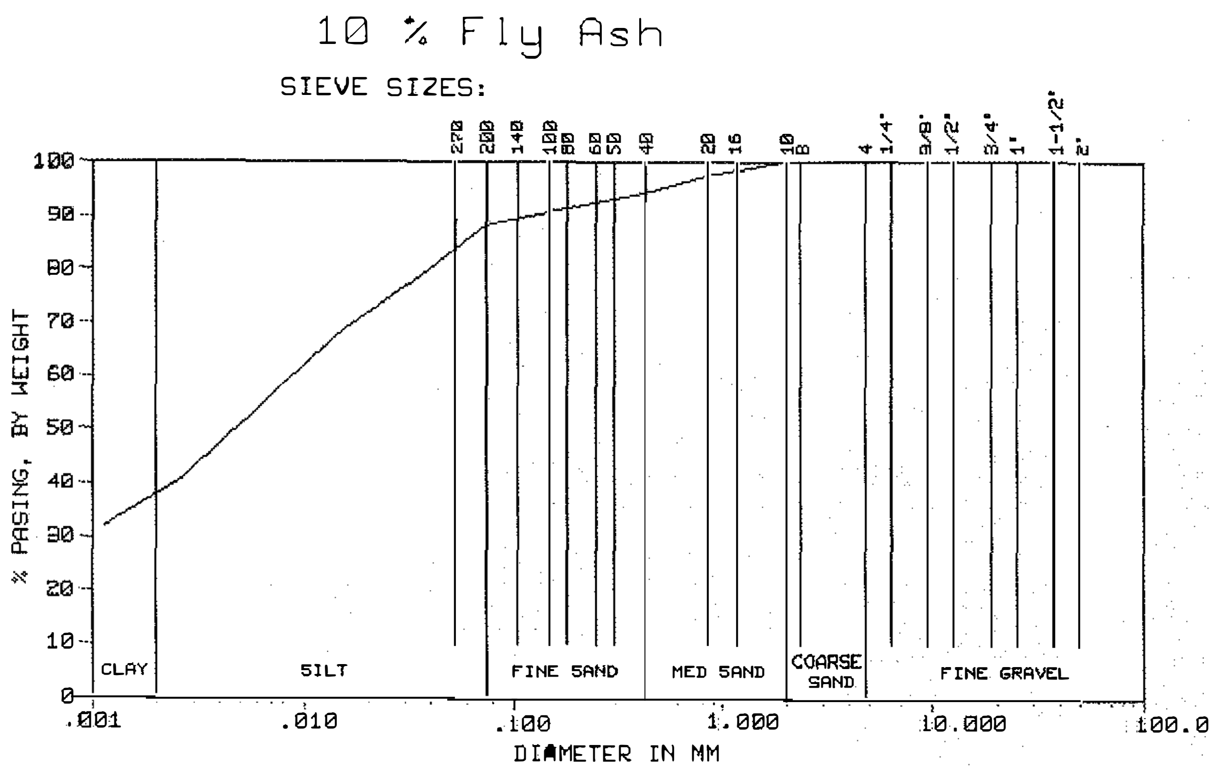

SIEVE SIZES:
270
200
140
100
80
60
50
40
20
16
10
8
4
1/4"
3/8"
1/2"
3/4"
1"
1-1/2"
2"
100
90
80
70
60
50
40
30
20
10
0
% PASSING, BY WEIGHT
CLAY
SILT
FINE SAND
MED SAND
COARSE SAND
FINE GRAVEL
.001
.010
.100
1.000
10.000
100.0
DIAMETER IN MM

3% Lime 10% Fly Ash

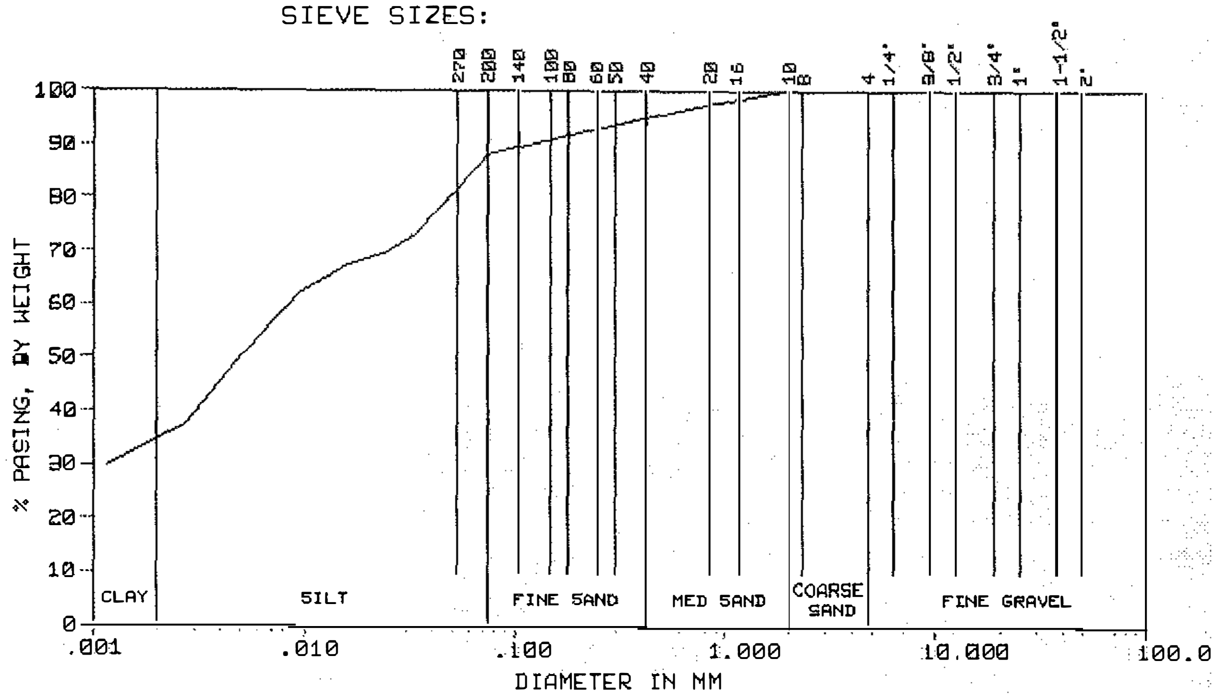




2% Lime 20% Fly Ash
SIEVE SIZES:
270
200
140
100
80
60
50
40
20
16
10
8
4
1/4"
3/8"
1/2"
3/4"
1"
1-1/2"
2"
% PASSING, BY WEIGHT
100
90
80
70
60
50
40
30
20
10
0
CLAY
SILT
FINE SAND
MED SAND
COARSE SAND
FINE GRAVEL
.001
.010
.100
1.000
10.000
100.0
DIAMETER IN MM


10 % Fly Ash
SIEVE SIZES:
270
200
140
100
80
60
50
40
20
16
10
8
4
1/4"
3/8"
1/2"
3/4"
1"
1-1/2"
2"
% PASSING, BY WEIGHT
100
90
80
70
60
50
40
30
20
10
0
CLAY
SILT
FINE SAND
MED SAND
COARSE SAND
FINE GRAVEL
.001
.010
.100
1.000
10.000
100.0
DIAMETER IN MM

20 % Fly Ash


SIEVE SIZES:
270
200
140
100
80
60
50
40
20
16
10
8
4
1/4"
3/8"
1/2"
3/4"
1"
1-1/2"
2"
100
90
80
70
60
50
40
30
20
10
0
% PASSING, BY WEIGHT
CLAY
SILT
FINE SAND
MED SAND
COARSE SAND
FINE GRAVEL
.001
.010
.100
1.000
10.000
100.0
DIAMETER IN MM

APPENDIX B
Moisture-Density Relations Curves

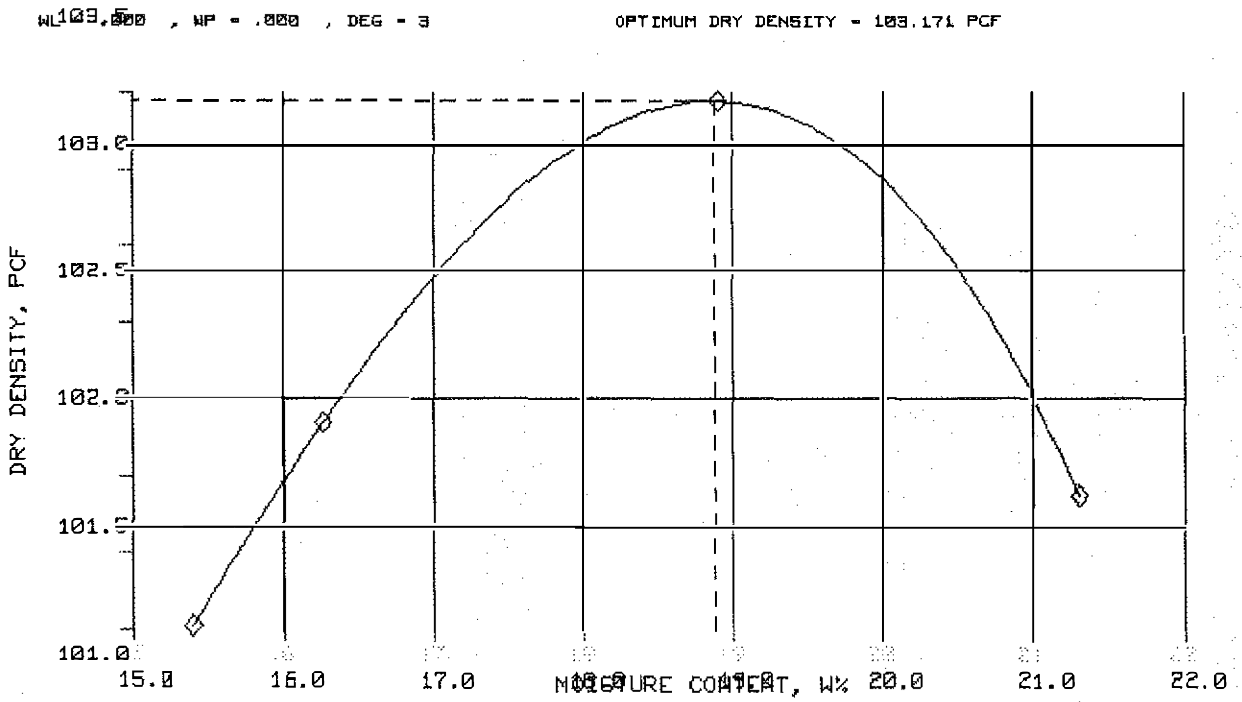
Soil

6-5-95

OPTIMUM MOISTURE CONTENT (%) = 18.880

WL = .000 , WP = .000 , DEG = 3

OPTIMUM DRY DENSITY = 103.171 PCF



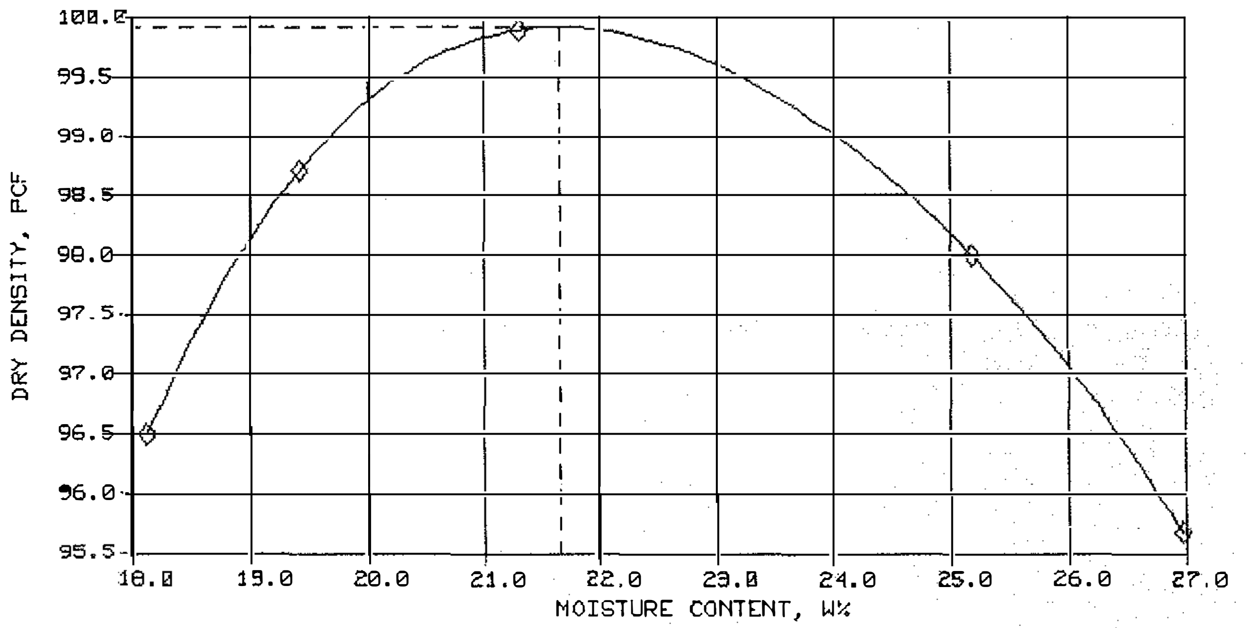
5% Lime

12-20-95

OPTIMUM MOISTURE CONTENT (%) = 21.661

WL = .000 , WP = .000 , DEG = 4

OPTIMUM DRY DENSITY = 99.922 PCF



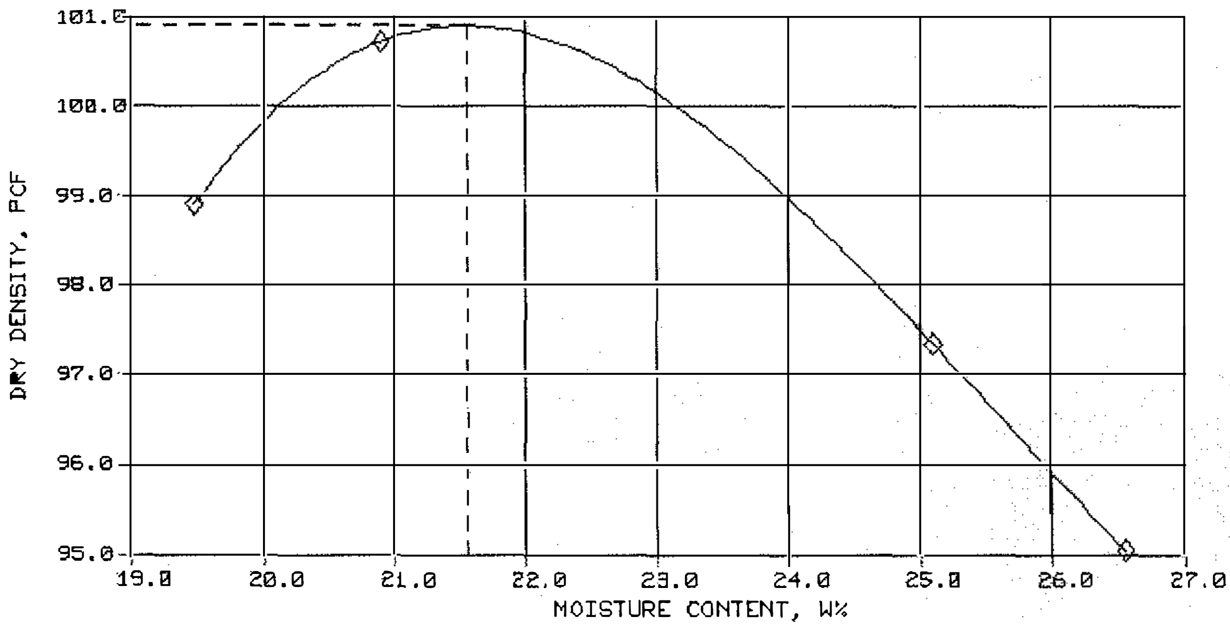
2% Lime 20% FA

1-24-96

OPTIMUM MOISTURE CONTENT (%) = 21.549

WL = .000 , WP = .000 , DEG = 3

OPTIMUM DRY DENSITY = 100.910 PCF



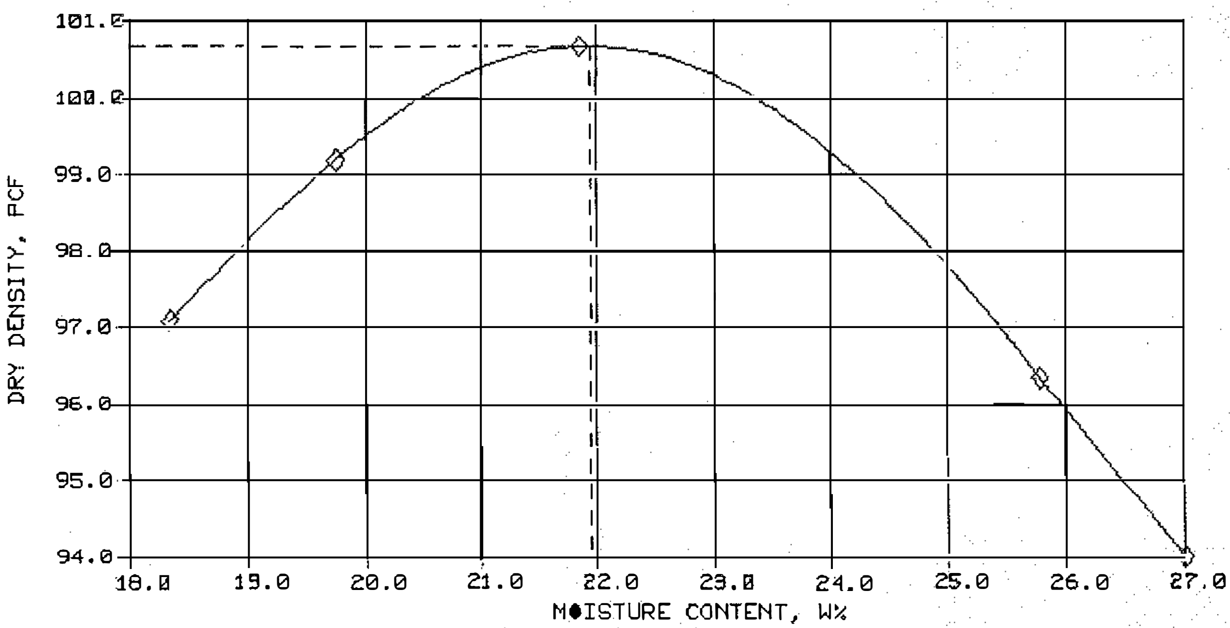
3% Lime 10% FA

12-21-95

OPTIMUM MOISTURE CONTENT (%) = 21.941

WL = .000 , WP = .000 , DEG = 4

OPTIMUM DRY DENSITY = 100.676 PCF



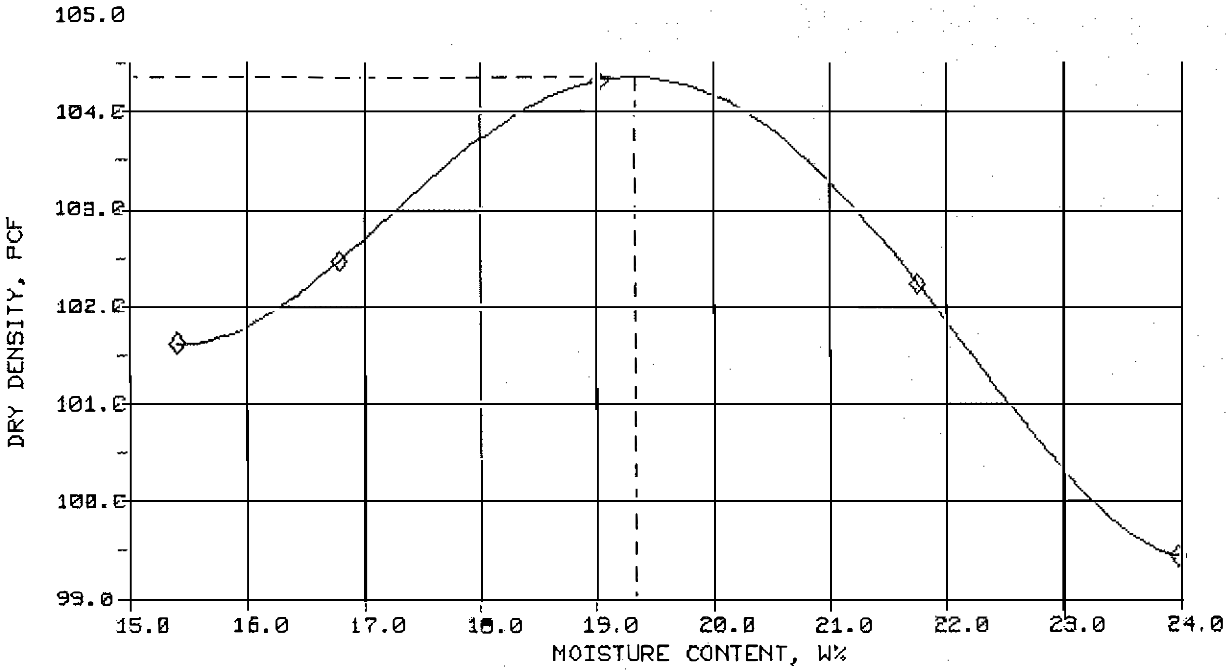
10 % Fly Ash

6-19-96

OPTIMUM MOISTURE CONTENT (%) = 19.334

WL = .000 , WP = .000 , DEG = 4

OPTIMUM DRY DENSITY = 104.363 PCF



20 % Fly Ash

1-02-97

OPTIMUM MOISTURE CONTENT (%) = 18.535

WL = .000 , WP = .000 , DEG = 4

OPTIMUM DRY DENSITY = 103.502 PCF