SOIL-LIME FLY ASH STABILIZATION RESEARCH

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ABSTRACT

This report describes the testing and evaluation of seven soils and two marginal base materials stabilized with various lime-fly ash (LFA) ratios. Each stabilized material was evaluated by the unconfined compression and splitting tensile test with curing time being a major variable. A durability test was developed and used to further evaluate these LFA mixtures.

Performance data were gathered on existing 18-year old LFA pavements. Diamond bit cores were extracted from these pavements and evaluated by unconfined compression.

As a result of this work an LFA Special Specification has been developed for submission to the Department's Specification Committee for approval. A new tentative test procedure has been developed for District use in evaluating LFA materials. This proposed test is entitled, "Recommended Laboratory Procedures for Investigating Strength Characteristics of Soils and Lime-Fly Ash (LFA) or Fly Ash (FA) Mixtures," and appears in Appendix B of this report.

Continued evaluation of LFA stabilization is recommended by constructing small field test sections. It is suggested that these "in-service" test sections will reveal construction procedures and pavement performance difficult to measure in a laboratory.

SUMMARY

Existing literature mainly concerned with northeastern fly ash is reviewed and evaluated. Data developed by the Materials and Tests Division on availability of fly ash in Texas are included.

Field construction data on existing 18-year old LFA stabilized pavements are presented. These pavements were cored and the average unconfined compression strengths are given for these pavement cores in Figure 5, page 24.

Seven soils with widely varying characteristics and two marginal base materials are triaxially rated for their remolded strengths and the results are shown in Table 3. These materials were LFA stabilized with percent fly ash and time in capillarity being the major variables. The effect of LFA stabilization on these nine materials was evaluated by the unconfined compression and splitting tensile tests and the results are presented in tabular and graphic form in Appendix A.

A durability test was devised and each LFA mixture was submitted to wetting and drying cycles. The results of this special testing are shown in Table 5.

A recommended special specification for "Lime-Fly Ash (LFA) Treatment for Materials in Place," was developed and is included as Appendix C to this report.

The findings herein are the results of tests upon hundreds of LFA specimens molded on standard laboratory compaction equipment. As a result of mixing, molding, curing and testing of these soils and marginal bases, using a range

of fly ash contents with each material, the relative strengths of each mixture were found. This information was used to develop a laboratory test procedure for evaluating fly ash and lime-fly ash mixtures. This new proposed test method is included as Appendix B of this report.

IMPLEMENTATION STATEMENT

It is recommended that the findings of this research be implemented by accomplishing the following tasks:

1. The Materials and Tests Division to review and approve the proposed test method included as Appendix B of this report.
2. The Department's Specification Committee to review the Special Specification for "Lime-Fly Ash (LFA) Treatment for Materials in Place," which is included as Appendix C of this report.
3. Continue research in LFA stabilization through the use of field test sections to surface correct design and construction procedures.
4. Consideration of LFA stabilization on construction and maintenance projects within economic haul distance of existing fly ash sources.

I. INTRODUCTION

Fly ash is a by-product of coal burning power plants and is the most commonly used pozzolan today. There are presently seven electrical power plants in Texas using lignite coal as their source of fuel. (1) The location, owner and fly ash production rate for these plants are shown in Table 1. Four of these plants have additional units planned and eight other coal fired plants are being planned and/or constructed in as many new locations. It is estimated that by 1982 there will be 5 million tons of fly ash produced annually in Texas. Disposal of this fly ash and additional bottom slag is, or will become, an environmental and engineering problem of increasing magnitude to producers.

TABLE 1

February 1, 1978

POWER PLANTS IN TEXAS PRODUCING FLY ASH *

Location	Owner	Fly Ash Production (tons/year)
Amarillo	SW Public Service	110,000
Mount Pleasant	Texas Power & Light	600,000
Cason	SW Public Service	110,000
Fairfield	Dallas Power & Light	400,000
Rockdale	ALCOA	200,000
San Antonio	San Antonio Public Service	400,000
Martin Lake	Texas Utilities	750,000
*Does not include bottom slag		2,570,000

Fly ash and/or bottom slag containing fly ash along with hydrated lime have been used in engineering applications for many years. Anticipating heavy wheel loads on their Farm-to-Market System near Aluminum Company of America's (ALCOA) plant located at Rockdale, District Seventeen employed this method of base construction in the late 1950's. ALCOA built a haul road in July 1959 using hydrated lime-bottom slag-fly ash to support Euclids with gross loads approaching 70,000 pounds. [2] As this report is being prepared, ALCOA has under construction another haul road using lime-fly ash subgrade stabilization.

Compacting Lime (4%) - Fly Ash (8%) and Subgrade Soil (88%) with a 70,000 pound Euclid on an ALCOA haul road in 1959.

Not all fly ashes have the same chemical properties. [3] The Materials and Tests Division is presently sampling and testing fly ash sources located in Texas. Physical [4] and chemical [5] data of a local fly ash source are shown in Table 2.

TABLE 2

DATA FOR A TEXAS FLY ASH		
Physical Tests	ASTM C 618-73 Specification	Test Results
Fineness	6500 cm^2/cm^3	12,640 cm^2/cm^3
Pozzolanic Activity Index:		
with Portland Cement	85	123
Water Requirement, %	105	91
Shrinkage, %	0.03	0.00
Soundness, Autoclave, %	0.05	0.02
Specific Gravity	-	2.66
Air Entrainment	-	1.11
Partial Chemical Analysis (Average of 2)		Percent
Silicon Dioxide (ASTM C 311)		37.0
Aluminum Oxide, Combined SiO_2, Al_2O_3, Fe_2O_3		3.7
Sulfur Trioxide (ASTM C 311)		0.4
Available Alkalies Na_2O (ASTM C 311)		0.4
Available Alkalies K_2O (ASTM C 311)		0.2
Moisture Content		0.1

The Austin White Lime Company supplied the hydrated lime used in this research. It met the requirements set forth in State Department of Highways and Public Transportation (SDHPT) Standard Specifications for Item 264, Type A, Hydrated Lime. [6]

In locations where lime is supplied at a lower cost than portland cement, lime-fly ash stabilization can often produce material of comparable long-term strength and durability at a reduced cost when compared to cement stabilization. [7] There are excessive amounts of fly ash and bottom slag presently being produced in Texas with major increases expected when proposed new power plants start production. It appears that it would be beneficial to the Department to research and use these construction materials within economical haul distance of the power plants shown in Table 1.

II. PURPOSE

The purpose of this research is to determine the effect of using hydrated lime and lignite fly ash in the stabilization of seven soils and two flexible bases. The research effort is supported with information on fly ash sources and data from existing highways utilizing lime-fly ash stabilization as their base course. It is anticipated that district laboratories throughout the Department will conduct additional stabilization research using the nearest source of fly ash on their soils and marginal base sources.

III. SCOPE

The scope of this research included:

A. Review of the literature concerning soil lime-fly ash (LFA) stabilization.

B. Location and sampling seven different soils and two marginal base materials in the vicinity of fly ash sources.

C. Completing identification tests on soils and stabilizers used in this research.

D. Planning laboratory testing for determination of relationships between unconfined compressive strength, splitting tensile strength and LFA contents with time in capillarity being a major variable.

E. Coring and evaluating existing pavements using LFA as a stabilizing agent.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

In general, the addition of lime and lignite fly ash is beneficial to the seven soils, two marginal base materials and existing LFA stabilized pavements investigated in this study. The specific conclusions reached during this investigation are summarized below.

1. The selection of lime and fly ash content is very important for successful LFA stabilization. The amounts of minus 0.05 mm sizes and voids in the material to be stabilized play important parts in the determination of the correct amount of LFA to use.
2. Materials stabilized with LFA possessed greater unconfined compression strengths than the same material stabilized with lime or with fly ash alone.
3. Materials stabilized only with fly ash from ALCOA located at Rockdale, Texas, exhibited no significant increase in strength as measured by the unconfined compression test.
4. Selection of hydrated lime content by Test Method Tex-121-E appears valid when allowance is considered for field distribution.
5. Stabilization with LFA is a usable construction procedure.

6. Existing 18-year old pavements in the Rockdale, Texas, area stabilized with lime, ALCOA slag aggregate and fly ash have given excellent performance.

B. Recommendations

1. That the Materials and Tests Division consider and approve the new test method included as Appendix B of this report.
2. That the Department's Specification Committee consider and approve the Special Specification for "Lime-Fly Ash (LFA) Treatment for Materials in Place," included as Appendix C of this report.
3. Continue investigating LFA stabilization by building field test sections to surface construction procedures, design considerations and additional pavement performance data not evaluated by this laboratory study.
4. Continue the long-term testing of this study and issue a supplemental report when finished.
5. That LFA contents be selected by design strengths and laboratory tests performed during the project planning stage.
6. That controlled density specifications be used with LFA stabilization.

V. MATERIALS

Seven soils and two marginal base materials located near existing fly ash sources were selected for this research. Table 3 shows the wide range of soil constants represented by these materials. The soil constants, gradation, unconfined compression strength and triaxial class were all performed according to existing Department test methods. Note that the seven soils were mostly minus 40 mesh sieve size with plasticity indexes ranging from 4 to 50.

TABLE 3

SUMMARY OF SOIL CONSTANTS AND LOCATION DATA ON SOILS

Lab. No.	LL	PI	SL	LS	SR	U.Comp. STRENGTH	Soil Binder	TRIAXIAL CLASS	AASHTO CLASS
74-151-R	24	4	22	0.6	1.62	5.7	93	4.0	A-2-4(0)
76-41-R	21	4	20	1.2	1.72	27.3	96	3.2	A-4(5)
74-150-R	25	7	18	3.5	1.75	21.6	99	3.4	A-2-4(0)
76-239-R	35	20	16	9.5	1.79	29.9	99	3.7	A-6(9)
76-2-R	37	23	12	12.2	1.95	14.8	96	4.4	A-6(11)
76-88-R	39	24	14	12.0	1.88	16.2	100	4.5	A-6(17)
76-22-R	71	50	10	23.8	2.07	4.2	99	5.9	A-7-6(54)
75-132-R	18	5	14	2.3	1.91	36.7	39	2.3	A-1-6(0)
77-7-R	29	14	14	8.1	1.95	21.7	45	3.0	A-6(2)

PERCENT RETAINED ON

Lab No.	Square Mesh Sieve															Grain Diam.			Specific Gravity
	Opening in Inches								Sieve Numbers							in Millimeters			
	3	2½	2	1¾	1¼	⅞	⅝	⅜	4	10	20	40	60	100	200	.05	.005	.001	
74-151-R										0	1	7	25	51	84	90	95	98	2.66
76-41-R											0	4	7	19	41	54	92	98	2.64
74-150-R											0	1	14	52	72	74	82	82	2.67
76-239-R										0	1	1	2	6	40	47	72	78	2.66
76-2-R										0	2	4	12	24	41	50	68	77	2.64
76-88-R												0	0	3	23	33	69	76	2.63
76-22-R											0	1	2	3	5	8	35	44	2.66
75-132-R							0	1	24	45	54	61	70	78	85	86	94	95	2.64
77-7-R					0	2	11	22	35	44	52	55	56	58	62	66	86	92	2.76

SAMPLE IDENTIFICATION

Lab. No.	Identification Marks	Location—Properties—Station Numbers	Type of Materials
74-151-R	Travis Co.	Old Bolm Pit on Webberville Road	Sand, Silty, Fine
76-41-R	Smith Co.	2.6 mi. S. of Sabine River on US 69	Sand, Silty, Fine
74-150-R	Leon Co.	1.4 mi. N. of Flynn on FM 39	Sand, Clayey
76-239-R	Limestone Co.	1.5 mi. W. of Mexia on US 84	Sand, Clayey
76-2-R	Lavaca Co.	3 mi. N.E. of Yoakum on FM 318	Clay, Sandy
76-88-R	Harris Co.	ROW Sta. 62+00 on SH 288	Clay, Sandy
76-22-R	Williamson Co.	ROW at Int. County Road and SH 95	Clay, Houston, Stiff Bl.
75-132-R	San Jacinto Co.	Washburn Pit, 2.5 mi.E.Walker Co.Ln.	Willis Iron Ore Gravel
77-7-R	Williamson Co.	3 mi. S. Georgetown on IH 35	Limestone, Clayey, Crushed

Fly ash used in this research was from the ALCOA source located approximately 4 miles southwest of Rockdale in Milam County. Comparative tests on selected lime-fly ash ratios were made using the Texas Utilities Generating Company's source near Fairfield in Freestone County. It is planned that this test data will be incorporated in a supplemental report when complete.

Two marginal base materials were selected with different physical and chemical characteristics. The crushed limestone has a plasticity index of 14, whereas the sandy iron ore has a plasticity index value of 4.

As previously stated, the hydrated lime was supplied by the Austin White Lime Company located near McNeil, Texas.

VI. EQUIPMENT

The tests performed in this research can be accomplished on equipment commonly located in a district laboratory. The large gyratory soils compactor or triaxial press can be substituted for the Tinius Olsen Machine used for unconfined compression testing in this research effort.

VII. PROCEDURE FOR ACQUIRING DATA

Selected Districts were contacted for assistance in locating and sampling the desired soils. The following test methods were used in sampling, preparing and testing each material: (8)

Test Method No. [8]	Title
Tex-100-E	Surveying and Sampling Soils for Highways.
Tex-101-E	Preparation of Soil and Flexible Base Materials for Testing.
Tex-104-E	Determination of Liquid Limit of Soils
Tex-105-E	Determination of Plastic Limit of Soils.
Tex-106-E	Method of Calculating Plasticity Index of Soils.
Tex-107-E	Determination of Shrinkage Factors of Soils.
Tex-108-E	Determination of Specific Gravity of Soils.
Tex-110-E	Determination of Hydrometer and Mechanical Analysis of Soils.
Tex-113-E	Determination of Moisture Density Relations of Soils and Base Materials.
Tex-117-E	Triaxial Compression Test for Disturbed Soils and Base Materials.
Tex-121-E	Soil-Lime Compressive Strength Test Methods.

Specimens used in this investigation were the 6 X 8 inch size described by Test Method Tex-113-E. A compactive effort of 13.26 ft lb/cu in. was used in molding these lime-fly ash test specimens. Approximately 906 of these specimens were compacted to investigate the effect of varying the fly ash content on seven soils and two marginal base materials. Percent hydrated lime for each material was selected by Test Method Tex-121-E, Figure 3, with the exception that 4.0 percent was the maximum considered for reasons of economy.

The unconfined compression test and the splitting tensile test were selected to evaluate the variable fly ash content. Each soil was investigated with 3, 4 and 7 parts fly ash to 1 part hydrated lime. Two unconfined compression strength test results were averaged for each data point. Splitting tensile strength data are represented by single test specimens. This laboratory test data is presented in tabular and graphical form in Appendix A by soil type.

Through this testing program, the effect of time in capillarity on the strength values of lime-fly ash mixtures was also evaluated. Unconfined strength tests were programmed after 10, 30, 90 and 180 days in capillarity. Results of the long term unconfined strength tests are to be included in a supplemental report when testing is complete.

One specimen was molded of each lime-fly ash percentage to evaluate the durability of these stabilized mixtures. These specimens were subjected to wetting and drying cycles using the moist room and 140 F laboratory oven. Specimens were evaluated visually and by volume change characteristics after each cycle.

Triaxial tests were completed on the seven soils and two marginal base materials without any stabilizing agent being added. Unconfined compression tests were run on selected materials using only hydrated lime as the stabilizing agent. Similar tests were completed using 100 percent fly ash.

Field cores were sampled from three lime-fly ash stabilized base courses in the Rockdale area. These cores were evaluated by unconfined compression and splitting tensile tests.

VIII. DISCUSSION OF TEST DATA AND RESULTS

A. Unconfined Compression

Table 4 lists a summary of compressive strength data which has been completed through 180 days of moist curing. Note that the 180 day compressive strengths varied from 53 psi for Test Number 76-41-R to 1395 psi for Test Number 77-7-R. The silty fine sand from Smith County represented by Test Number 76-41-R contained 46 percent minus 0.05 mm material. This large surface area along with the low percentage of hydrated lime used contributed to this low break. The triaxial class 2.5 crushed limestone represented by Test Number 77-7-R contained a large amount of calcium which contributed to its higher strength. Because of the great variations in soils located in Texas, it is recommended that a soil profile be developed along with detailed soil tests to assist the pavement designer in selecting the correct lime-fly ash percentage and ratio.

B. Design and Testing

The literature on LFA stabilization, which was validated by this research, indicated the voids in the material should be overfilled approximately 3 percent with the selected LFA blend to float the soil particles. The strength of these stabilized materials depends on a well designed matrix. Extrapolation of test results from one project to another to predict performance of mixtures containing different soils may not be valid. (9) Laboratory tests must be completed to obtain the proper proportions and the most economical mix design. This again illustrates the importance of having the district laboratories investigate the correct LFA blend to use with local soils in respective Districts.

TABLE 4

SUMMARY OF 180 DAY COMPRESSION STRENGTHS

Test Number	Lime Content(%)	Fly Ash Content(%)	Compression Strength (psi)
74-151-R	1.5	4.5	204
	1.5	6.0	284
	1.5	10.5	349
76-41-R	1.5	4.5	53
	1.5	6.0	63
	1.5	10.5	69
74-150-R	1.5	4.5	234
	1.5	6.0	208
	1.5	10.5	268
76-239-R	3.0	9.0	257
	3.0	12.0	324
	3.0	21.0	396
76-2-R	3.5	10.5	681
	3.5	14.0	698
	3.5	24.5	844
76-88-R	3.0	9.0	541
	3.0	12.0	604
	3.0	21.0	682
76-22-R	4.0	12.0	596
	4.0	16.0	609
	4.0	28.0	658
75-132-R	2.0	6.0	123
	2.0	8.0	200
	2.0	14.0	301
77-7-R	2.5	7.5	1283
	2.5	10.0	1120
	2.5	17.5	1395

Four soil materials were selected to demonstrate the effect of increasing the fly ash content in LFA stabilization. Figure 1 is a plot of compression strength at 90 days versus material finer than 0.05 mm in the test specimen. Generally, increased fly ash content increased the unconfined compression strength over the range of soils investigated as shown in Figure 1. This has also been documented by previous research of eastern fly ashes. (10) Again note that Test Number 76-41-R contained insufficient lime and fly ash to fill the voids and coat each soil particle. Also, high relative density is critical for high strength and durability. (11) Compaction is most important in obtaining desired performance of LFA pavements. For this reason controlled density is recommended for highway projects using LFA stabilization.

Test Number 76-88-R, Figure 2, was selected to show the realtionship between the variables (1) time in capillarity and (2) fly ash content as measured by the unconfined compression strength. Strength varied directly with time in capillarity and increased amounts of fly ash.

Note that this Harris County sandy clay tested 541 psi when stabilized with 3.0 percent hydrated lime and 9.0 percent fly ash. This exceeds the 500 psi required for stabilized base materials by some special specifications. However, these stabilized subgrade materials should not be used for bases without being documented with test sections built on the highway system and subjected to existing traffic.

FIGURE 1

STRENGTH VERSUS MINUS 0.05 mm MATERIAL

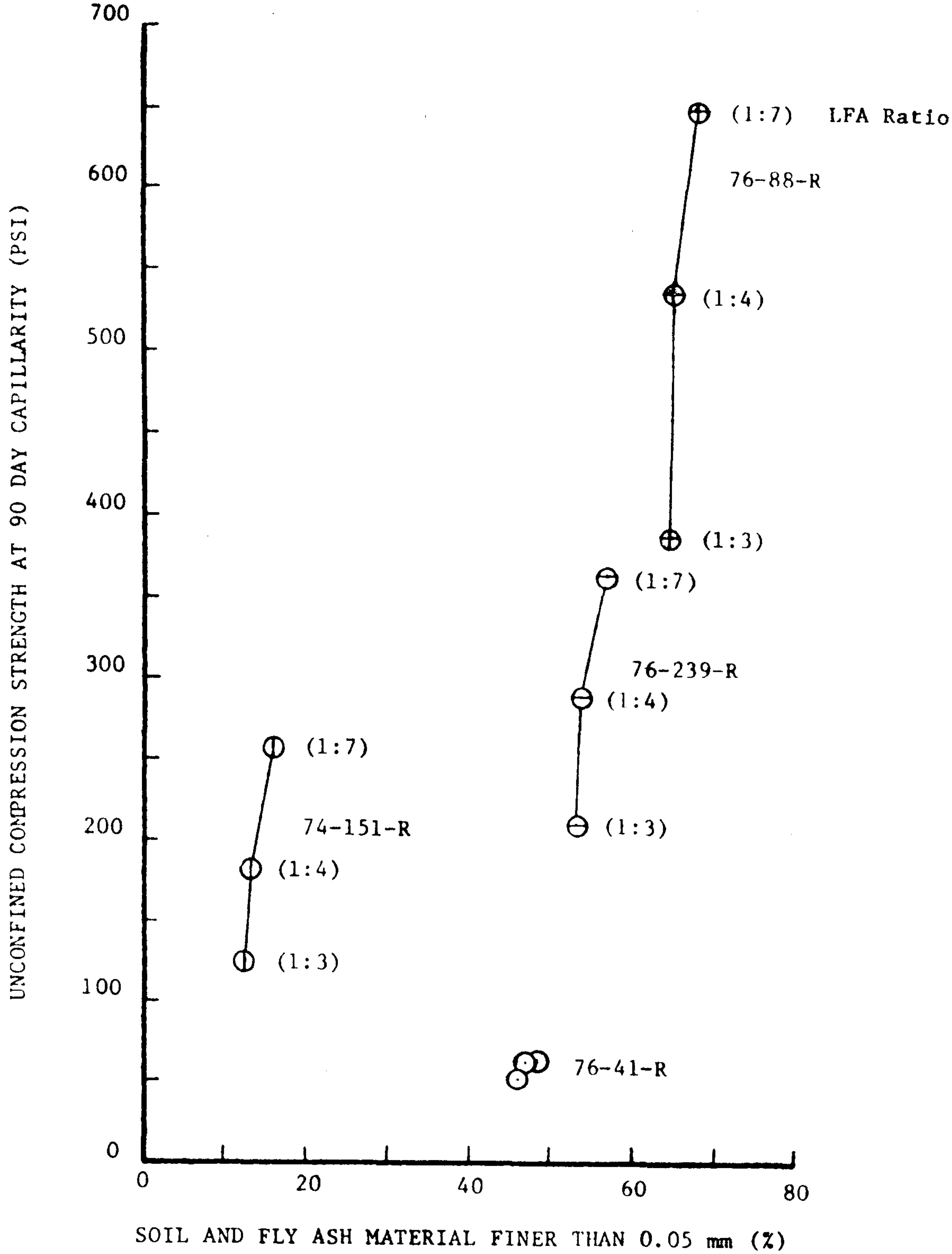
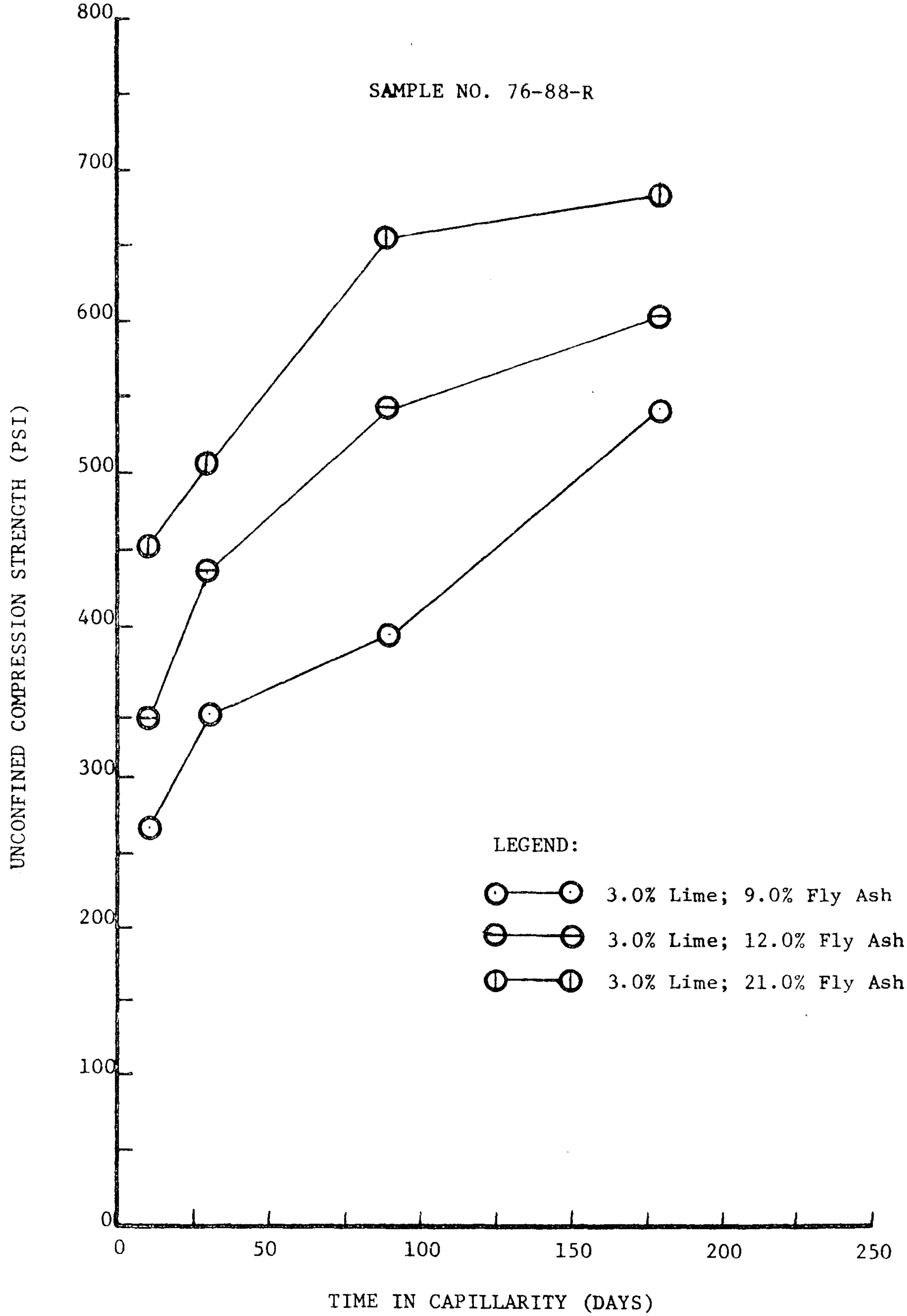


FIGURE 2

STRENGTH VERSUS TIME IN CAPILLARITY



C. Recommended Laboratory Procedures

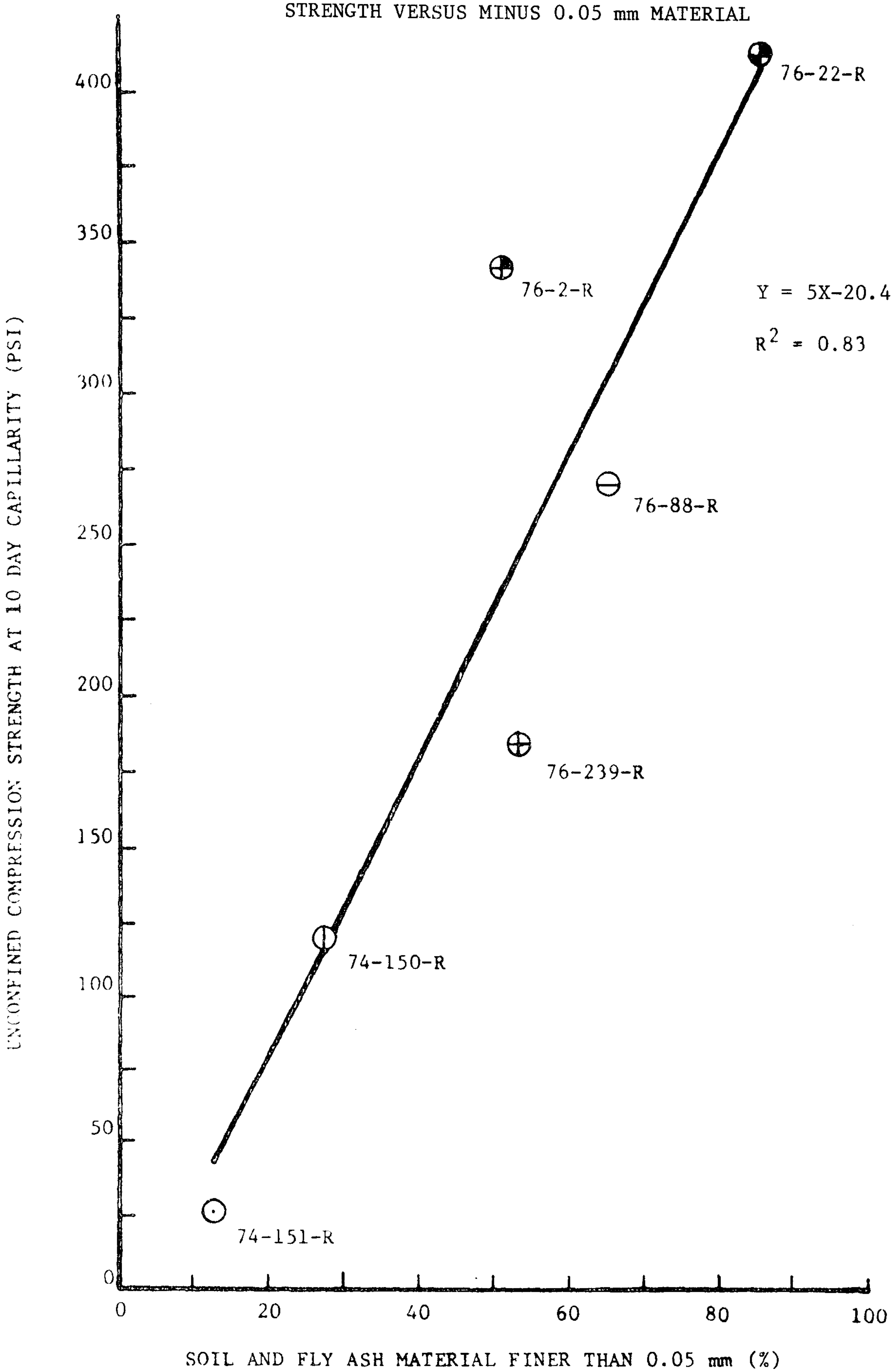
The percentage of grain sizes finer than 0.05 mm in the soil and fly ash was calculated from Test Method Tex-110-E test results. Figure 3 gives a relationship between the material finer than 0.05 mm and the unconfined compression strength at 10 days capillarity for six of the seven soils investigated. The soil represented by 76-41-R was deleted from consideration because of its high silt and low hydrated lime content. The relatively high correlation index (R^2) value of 0.83 obtained was restricted to test values at 10 day capillarity. As pozzolanic cementation continued with passage of time, test data scatter increased and R^2 values were reduced for long term tests. For these reasons the procedure outlined in Appendix B for estimating strength values of lime-fly ash stabilized materials is recommended.

D. Durability

Durability studies were performed on five of the seven soils and one base material. Specimens were subjected to a drying and wetting cycle whenever strength measurements were made, namely at 10, 30, 90 and 180 days. Durability testing will continue on specimens receiving 360 and 720 days of curing. Wetting was accomplished by placing the unprotected specimens in a moist room without allowing time for moisture equalization after drying. This constitutes a severe test and probably explains the spalling occurring on the outside of specimens molded with clayey soils. Drying was accomplished in a 140 F oven until one-third to one-half of the molding moisture had been removed. This required approximately 6 hours drying time. Test data of this durability evaluation are shown in Table 5.

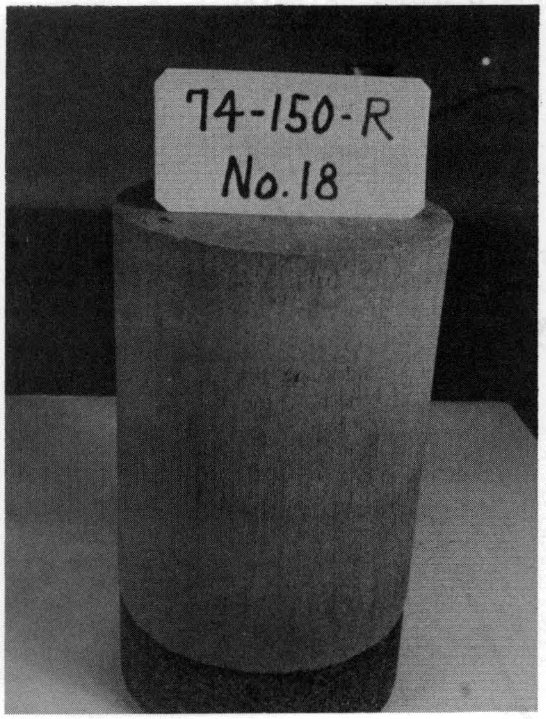
FIGURE 3

STRENGTH VERSUS MINUS 0.05 mm MATERIAL

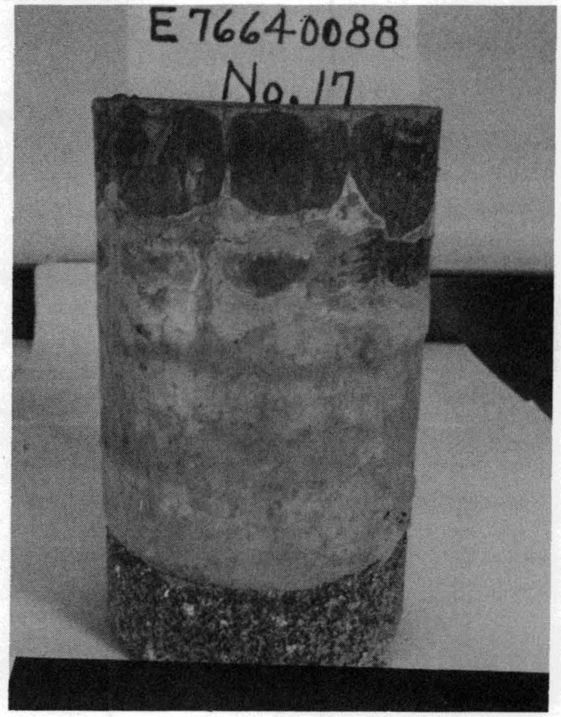


LIME: FLY ASH RATIO IS 1:3

Figure 4



Appearance of the LFA stabilized Leon County clayey sand after 3 cycles of wetting and drying (90 days). This material has maintained this excellent appearance throughout the durability testing.



Appearance of the LFA stabilized Harris County sandy clay (76-88-R) after 5 cycles of wetting and drying (360 days). Note the apparent sealing of the dry shrinkage cracking by the phenomenon called autogenous healing, which is one of the unique properties of LFA mixtures.

Appearance of the LFA stabilized Williamson County Houston black clay (76-22-R) after 4 cycles of wetting and drying (180 days). Note the severe spalling of material located between the tamping head and the inside of the compaction mold. The durability testing was discontinued after 5 cycles and the specimen tested 383.3 psi in unconfined compression.

TABLE 5

WET-DRY DURABILITY RESULTS

Test Number	Unconfined Compression (%)	No. Wet-Dry Cycles	Vol. Swell (%)	Raw Soil PI	LFA Ratio	Lime Content (%)	Remarks
76-41-R-29	-	6	0.03	4	1:3	1.5	Sound
76-41-R-56	-	6	Nil	4	1:4	1.5	Sound
76-41-82	-	6	Nil	4	1:7	1.5	Sound
74-150-R-18	-	6	0.66	7	1:3	1.5	Sound
74-150-R-50	-	6	0.06	7	1:4	1.5	Sound
74-150-R-90	-	6	0.10	7	1:7	1.5	Sound
76-239-R-27	-	5	0.05	20	1:3	3.0	Slight Spalling
76-239-R-53	-	5	0.12	20	1:4	3.0	Slight Spalling
76-239-R-96	-	5	0.00	20	1:7	3.0	Slight Spalling
76-88-R-17	-	6	0.14	24	1:3	3.0	Slight Spalling
76-88-R-50	-	6	0.11	24	1:4	3.0	Slight Spalling
76-88-R-77	-	6	0.21	24	1:7	3.0	Slight Spalling
76-22-R-13	295.2	5	3.12	50	1:3	4.0	Spalling
76-22-R-47	383.3	5	3.03	50	1:4	4.0	Spalling
76-22-R-72	-	6	Nil	50	1:7	4.0	Spalling
77-7-R-26	-	5	Nil	14	1:3	2.5	Sound
77-7-R-54	-	5	Nil	14	1:4	2.5	Sound
77-7-R-93	-	5	Nil	14	1:7	2.5	Sound

Slight spalling has been observed on specimens with initial plasticity indexes in the teens. Specimens represented by Test Numbers 76-22-R-13 and 76-22-R-47 were spalling to the extent that durability testing was discontinued after 5 cycles and they were tested in unconfined compression. These specimens retained 49.5 and 62.9 percent of the strength respectively of specimens of the same age subjected only to moist curing. All specimens will be tested in unconfined compression after 7 wetting and drying cycles. These results will be issued as a supplement to the report when completed.

One must remember that this is a durability study conducted in a laboratory environment. This durability testing should be supplemented with road test sections to determine if LFA stabilization will perform in the same manner under field conditions.

E. Laboratory Test Data

Triaxial tests were completed on all soils and base materials used in this investigation following the procedures outlined in Test Method Tex-117-E. These triaxial strength results are located in Table 3. Table 6 gives the desired moisture and density of these LFA mixtures as determined by Test Method Tex-114-E. Note that the 1:4 LFA ratio could be utilized to develop the moisture-density relationships. Other LFA ratios could be investigated on the same material without developing additional moisture-density curves.

Comparison of stabilization agents: The zero lateral break was used to compare strength improvement of two soils and one marginal base material when stabilized with lime, fly ash and a combination of lime and fly ash.

TABLE 6

DESIRED MOISTURE AND DENSITY OF VARIOUS LFA STABILIZED MATERIALS

Test Number	Lime-Fly Ash Ratio	Desired Moisture	Desired Density
74-151-R	1:3	14.0	105.7
74-151-R	1:4	14.6	106.4
74-151-R	1:7	14.6	105.9
76-41-R	1:3	10.8	116.4
76-41-R	1:4	11.3	116.2
76-41-R	1:7	11.7	114.8
74-150-R	1:3	12.6	119.0
74-150-R	1:3	13.0	118.6
74-150-R	1:7	13.5	117.6
76-239-R	1:3	17.6	107.9
76-239-R	1:4	17.4	108.4
76-239-R	1:7	17.2	107.7
76-2-R	1:3	16.5	107.7
76-2-R	1:4	17.0	107.7
76-2-R	1:7	16.5	107.5
76-88-R	1:3	17.4	106.9
76-88-R	1:4	18.0	106.2
76-88-R	1:7	17.8	105.3
76-22-R	1:3	26.0	91.8
76-22-R	1:4	24.3	92.2
76-22-R	1:7	22.3	92.7
75-132-R	1:3	8.5	134.4
75-132-R	1:4	8.2	133.5
75-132-R	1:7	8.2	131.6
77-7-R	1:3	9.6	127.2
77-7-R	1:4	10.3	126.1
77-7-R	1:7	10.6	124.2

Unconfined compression and splitting tensile results are shown in Table 7 for the 10 and 30 days in capillarity curing periods. Note the added fly ash actually tested lower than the raw strength of Test Number 74-150-R. Hydrated lime increased the unconfined compression strength of all materials but was less effective on the low plasticity index clayey sand. The combination of lime-fly ash increased the unconfined compression and splitting tensile test values in all cases over that obtained using a single stabilizer. This combination of stabilizers has the added advantage of continued strength gain with additional passage of time if adequate amounts of lime and fly ash have been used. Strength values listed in Table 7 again highlight the importance of sufficient laboratory tests to select the right amount of stabilizing agents to use with the material proposed for stabilization.

F. Modulus of Elasticity

Typical modulus of elasticity values for LFA mixtures range from 0.5×10^6 to 2.5×10^6 psi. (12) Modulus of elasticity values will be measured on the specimens subjected to 720 days of capillarity and these values will be included in a supplemental report to this study.

G. Performance of LFA Roads

In 1959, a joint venture between the Industrial Generating Company (IGC) and the Aluminum Company of America (ALCOA) placed under construction a haul road utilizing the principal of LFA stabilization. The design consisted of 6 inches of sandy clay stabilized with 4.0 percent hydrated lime and 8.0 percent fly ash used as a subbase. The base course consisted of 6 inches of ALCOA slag aggregate and fly ash stabilized with 4.0 percent hydrated lime. These base courses were

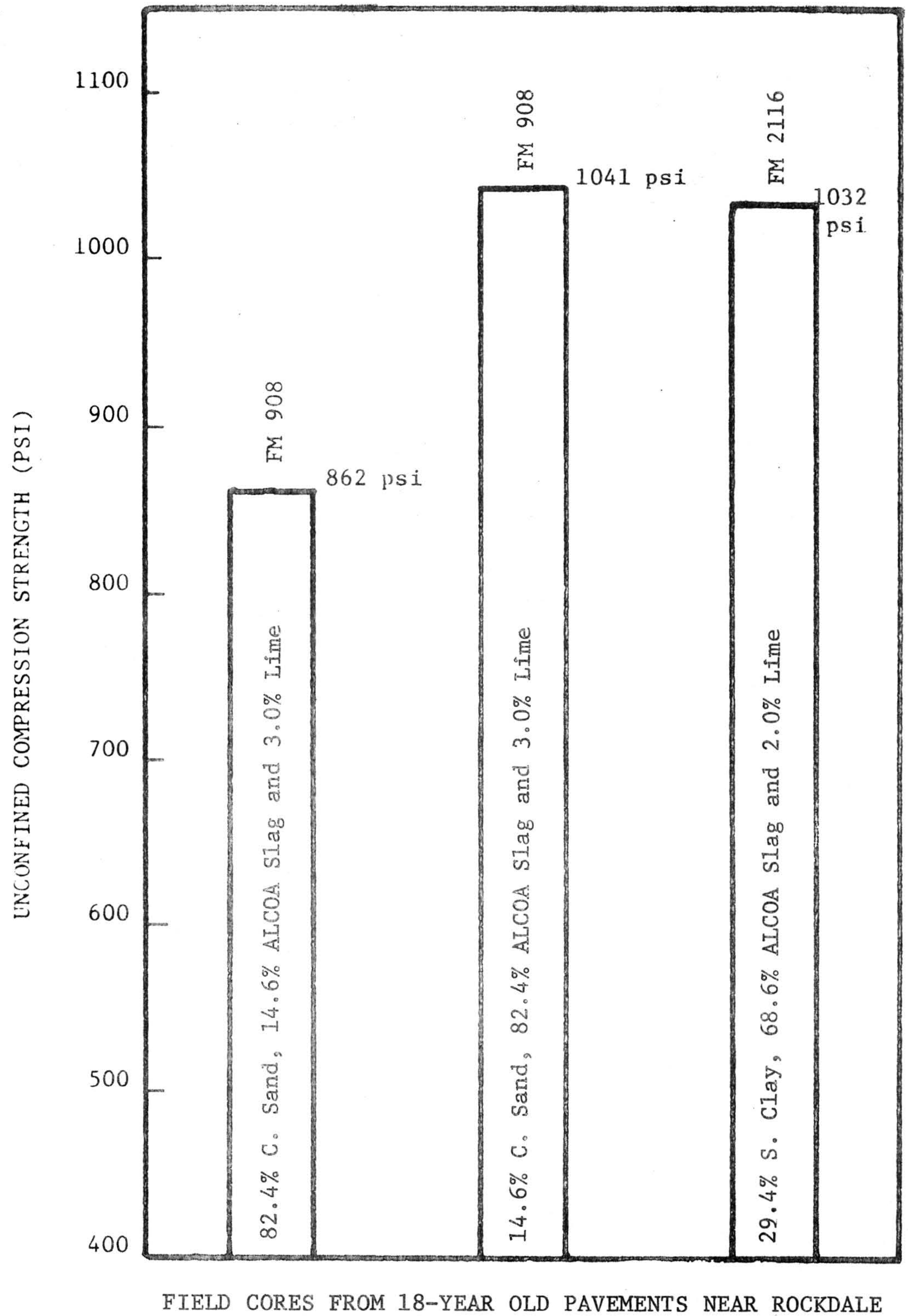
TABLE 7

COMPARISON OF STRENGTH USING LIME OR FLY ASH
OR A COMBINATION OF LIME AND FLY ASH

Capillarity (Days)	Lime Content (%)	Fly Ash Content (%)	Unconfined Compression (psi)	Splitting Tensile (psi)	
74-150-R (Plasticity Index equals 7; Clayey Sand from Leon County					
10	0.0	0.0	21.6	-	(Raw Soil)
10	1.5	0.0	84.7	6.4	
30	1.5	0.0	88.2	6.4	
10	0.0	6.0	12.2	3.2	
30	0.0	6.0	12.3	3.7	
10	1.5	6.0	134.7	10.0	
30	1.5	6.0	158.7	15.5	
76-239-R (Plasticity Index equals 20; Sandy Clay from Limestone County					
10	0.0	0.0	29.9	-	(Raw Soil)
10	3.0	0.0	105.0	10.8	
30	3.0	0.0	126.5	13.5	
10	0.0	12.0	75.3	8.9	
30	0.0	12.0	98.8	12.9	
10	3.0	12.0	210.1	28.0	
30	3.0	12.0	222.5	31.2	
77-7-R (Plasticity Index equals 14; Marginal Crushed Limestone from Travis Co.					
10	0.0	0.0	21.7	-	(Raw Soil)
10	2.5	0.0	302.9	34.8	
30	2.5	0.0	462.7	52.6	
10	0.0	10.0	114.0	11.3	
30	0.0	10.0	116.2	14.7	
10	2.5	10.0	562.5	68.6	
30	2.5	10.0	605.1	81.0	

FIGURE 5

STRENGTH OF EXISTING LFA PAVEMENTS



compacted and proof-rolled with loaded Euclid haul units weighing approximately 70,000 pounds. A sanded RC-2 prime was used to cure this 12-inch stabilized haul road and act as the wearing course. Construction was completed on July 11, 1959. The Texas Utilities Generating Company at Fairfield turned to LFA stabilization after their haul road employing conventional stabilization failed from loads of their lignite haul units. The success of this method of construction is proven by the fact that IGC and ALCOA presently have another haul road under construction using LFA stabilization in the pavement section to support the numerous heavy wheel loads expected from their large lignite haul units.

On July 22, 1959, a successful bid was submitted by the Larson Construction Company to build 6.2 miles of FM 908, starting at Blackjack and continuing northwest toward Rockdale. (13) The foundation course for this project consisted of mixing 26,550 cubic yards of clayey sand from the Allen pit with 4,680 cubic yards of ALCOA fly ash and slag and stabilizing this mixture with 3.0 percent lime. A short test section was constructed by Resident Engineer Richard Qualtrough where the rates of clayey sand and fly ash were reversed. Diamond bit cores were extracted from these pavements on October 25, 1977 and tested in unconfined compression. Average strength of the cores from these 18-year old pavements were 862 psi and 1041 psi respectively as shown in Figure 4. These pavements have never been reworked, but have received periodic seal coats.

In October 1960, a successful bid was submitted for the construction of FM 2116 from US 77 south of Rockdale, southwest toward ALCOA's plant for a distance of 2.5 miles. ALCOA's fly ash and slag aggregate was mixed with clayey gravel salvaged from the existing county road to form a 6-inch subbase. The base course consisted of adding 2.0 percent hydrated lime to a blend of 25 cubic yards per station of sandy clay from the Pearson pit with 55 cubic yards per station of ALCOA's fly ash and slag aggregate. This LFA stabilized base was also cored on October 25, 1977 and averaged 1032 psi in unconfined compression. This highway appears to have received a 1-inch layer of hot mix asphaltic concrete made with ALCOA's slag aggregate since its original construction was completed in 1961.

No pavement failures or surface cracks were noted during the coring of these pavements. However, several cracks were encountered in coring the 82.4 percent clayey sand, 14.6 percent ALCOA slag and 3.0 percent hydrated lime base on FM 908. A major base haul to US 77 was routed over this LFA stabilization project soon after its construction. This early loading may account for the number of base cracks encountered during coring. The subject of shrinkage cracking of LFA mixtures was not addressed in this laboratory research effort since it was felt this phenomenon could best be studied with additional research using field test sections.

New lignite fueled power plants normally utilize LFA and bottom slag in the construction of their pit roads to support large lignite haul units. Texas highways have given excellent pavement performance when constructed with LFA stabilization. It appears logical that proposed highway construction, contract or maintenance, within economic haul distance of lignite fueled power plants should seriously consider the use of LFA stabilization in the pavement structure.

District 15 has recently received an approved field change to incorporate LFA stabilization test sections in their active Project RS 3073(3) located on SH 85 in Frio County. They have plans to use LFA stabilization in the base and subgrade while varying the percentages of lime and fly ash. Additional preliminary laboratory investigations and test sections by other Districts located near a lignite-fueled power plant are highly recommended. These field test sections are needed to surface problems connected with construction and performance. These include, but are not necessarily limited to the following areas of needed information:

1. To gain information that would be useful in drafting a special specification on LFA stabilization.
2. Determine the lime-fly ash ratio and content to use on various soils and bases around each power plant.
3. Develop construction equipment and procedures to minimize the dust problem connected with LFA stabilization.
4. Develop design and construction procedures to minimize cracking and maximize density.
5. Develop procedures to insure a bond between the surfacing and LFA stabilized bases.
6. Study the construction time allowed on various LFA mixtures.
7. Study the sequence of adding lime, fly ash and water to various materials.
8. Gain additional performance data on LFA stabilization.

IX. IMPLEMENTATION

It is recommended that Districts within economical haul of lignite fueled power plants initiate LFA stabilization research in their district laboratories following the guidance outlined in Appendix B. This would give respective Districts insight on their fly ashes when used on their local soils and marginal base sources. It is further recommended that Districts utilize this additional research information to construct test sites by contract or with their maintenance forces. Lime-fly ash stabilization could then be considered for major contract projects provided the test section evaluations prove successful.

Implementation will be enhanced upon the completion of a special specification on fly ash by the Materials and Tests Division. This special specification should be included in the next revision of the Department's Standard Specifications.

A special specification on lime-fly ash stabilization has been prepared and is included in this report as Appendix C. It is envisioned that this specification will undergo changes as test section information from the Districts becomes available.

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XI. ACKNOWLEDGEMENTS

The assistance given by personnel of Districts 9, 10, 11, 12, 14, 17 and 19 in securing the soil and marginal base samples is gratefully acknowledged.

Special thanks go to the members of Section E, Materials and Tests Division. Their untiring efforts and interest in sampling, molding and testing the lime-fly ash mixtures used in this investigation were very gratifying. Their major contributions were as follows: Avery W. Smith, for obtaining research approval and experimental design; Charles E. O'Dell, for sampling and test calculations; Weldon E. Burklund and Charles E. Randal for scheduling, molding and testing the 906 specimens required for this research effort; John D. Bennight, for soil constants and pH values; and Gordon D. Greer, Lawrence R. Hester, Frank E. Herbert and Kenneth A. Dyer for graph preparation and computer analysis.

Appreciation is due Pat Hardeman and Jim Anagnos of the Center for Highway Research for their assistance in developing the indirect tensile data.

Thanks go to other Sections of the Materials and Tests Division for their usual input and outstanding support. Special thanks go to Mr. Larry G. Walker for providing guidance and the excellent atmosphere for this research effort.

Mrs. Elenora Dickens earned special gratitude for her patient editing and typing of the report.

NOTE: A. W. Smith, C. E. O'Dell, and K. A. Dyer have retired.

APPENDIX A, TAB. 1

TABULATION OF UNCONFINED COMPRESSION (UC) AND SPLITTING TENSILE (ST) TEST RESULTS ON LFA STABILIZED BASES AND SOILS (PSI)

			Days in Capillarity							
			10		30		90		180	
Test Number	Lime Content %	Fly Ash Content %	UC	ST	UC	ST	UC	ST	UC	ST
74-151-R	1.5	4.5	26	1	48	5	124	18	204	32
	1.5	6.0	43	4	80	9	182	23	284	44
	1.5	10.5	79	6	133	*	259	*	349	*
76-41-R	1.5	4.5	46	3	47	3	51	3	53	4
	1.5	6.0	50	4	53	4	61	4	63	4
	1.5	10.5	54	4	59	4	62	3	69	6
74-150-R	1.5	4.5	120	11	170	19	205	23	234	23
	1.5	6.0	135	10	159	16	199	20	208	27
	1.5	10.5	145	13	173	15	219	21	268	28
76-239-R	3.0	9.0	184	18	168	25	212	31	257	43
	3.0	12.0	210	28	223	31	289	36	324	43
	3.0	21.0	277	35	326	36	363	51	396	60
76-2-R	3.5	10.5	342	32	397	51	553	86	681	86
	3.5	14.0	327	45	388	69	529	82	698	92
	3.5	24.5	438	55	527	*	718	94	844	98
76-88-R	3.0	9.0	269	29	341	51	393	66	541	87
	3.0	12.0	340	38	437	50	541	68	604	92
	3.0	21.0	452	46	506	45	655	58	682	103
76-22-R	4.0	12.0	413	23	407	33	488	42	596	55
	4.0	16.0	428	43	459	42	565	45	609	45
	4.0	28.0	442	38	526	50	642	43	658	37
75-132-R	2.0	6.0	105	9	108	8	122	13	123	13
	2.0	8.0	146	15	173	12	189	19	200	15
	2.0	14.0	217	19	248	17	278	*	301	26
77-7-R	2.5	7.5	543	64	603	78	1014	137	1283	136
	2.5	10.0	563	69	605	81	898	125	1120	150
	2.5	17.5	639	84	804	91	1171	125	1395	181

NOTE: *Specimens not molded and tested.

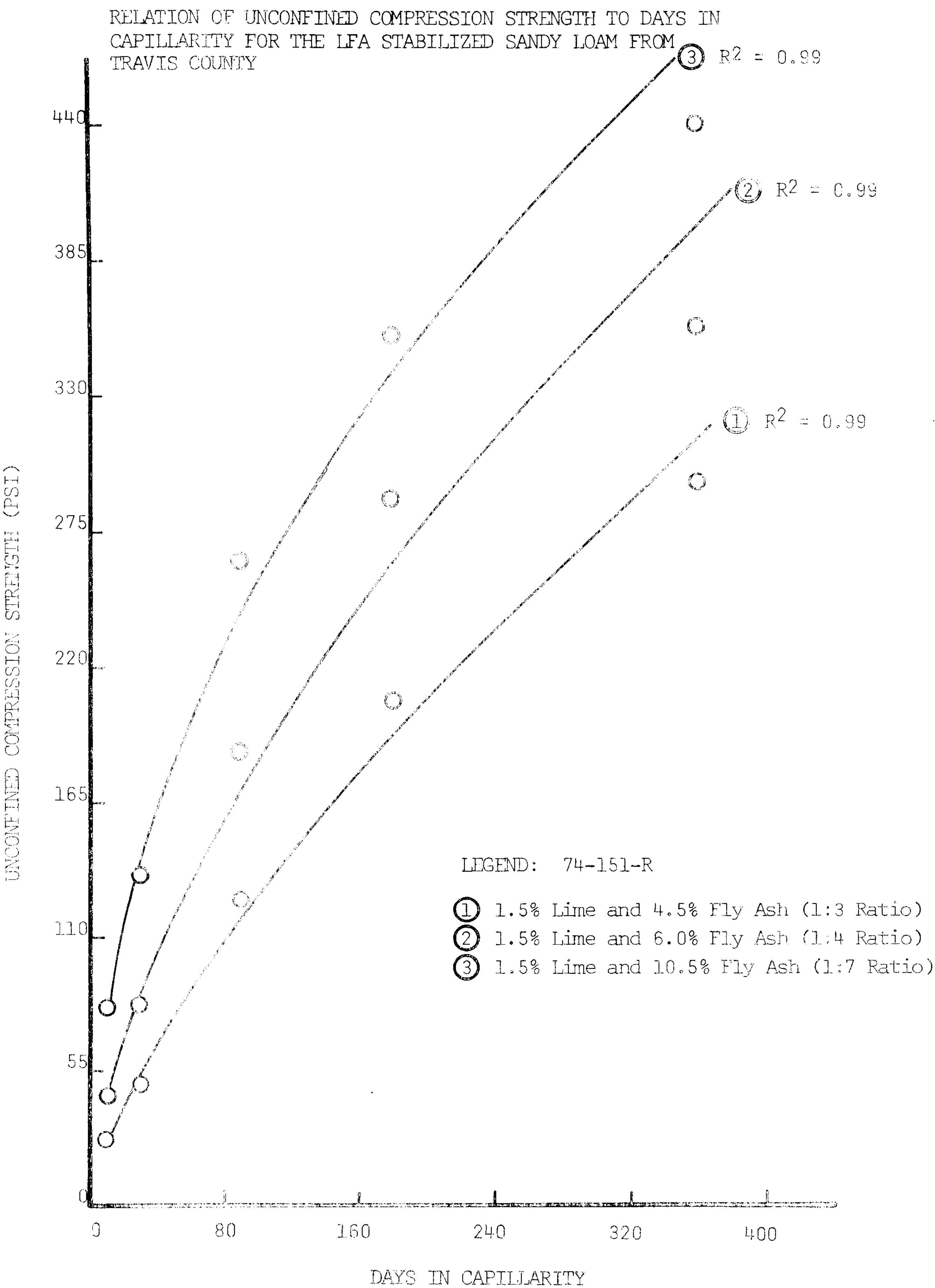
APPENDIX A, TAB. 2

GRAPHICAL PRESENTATION OF

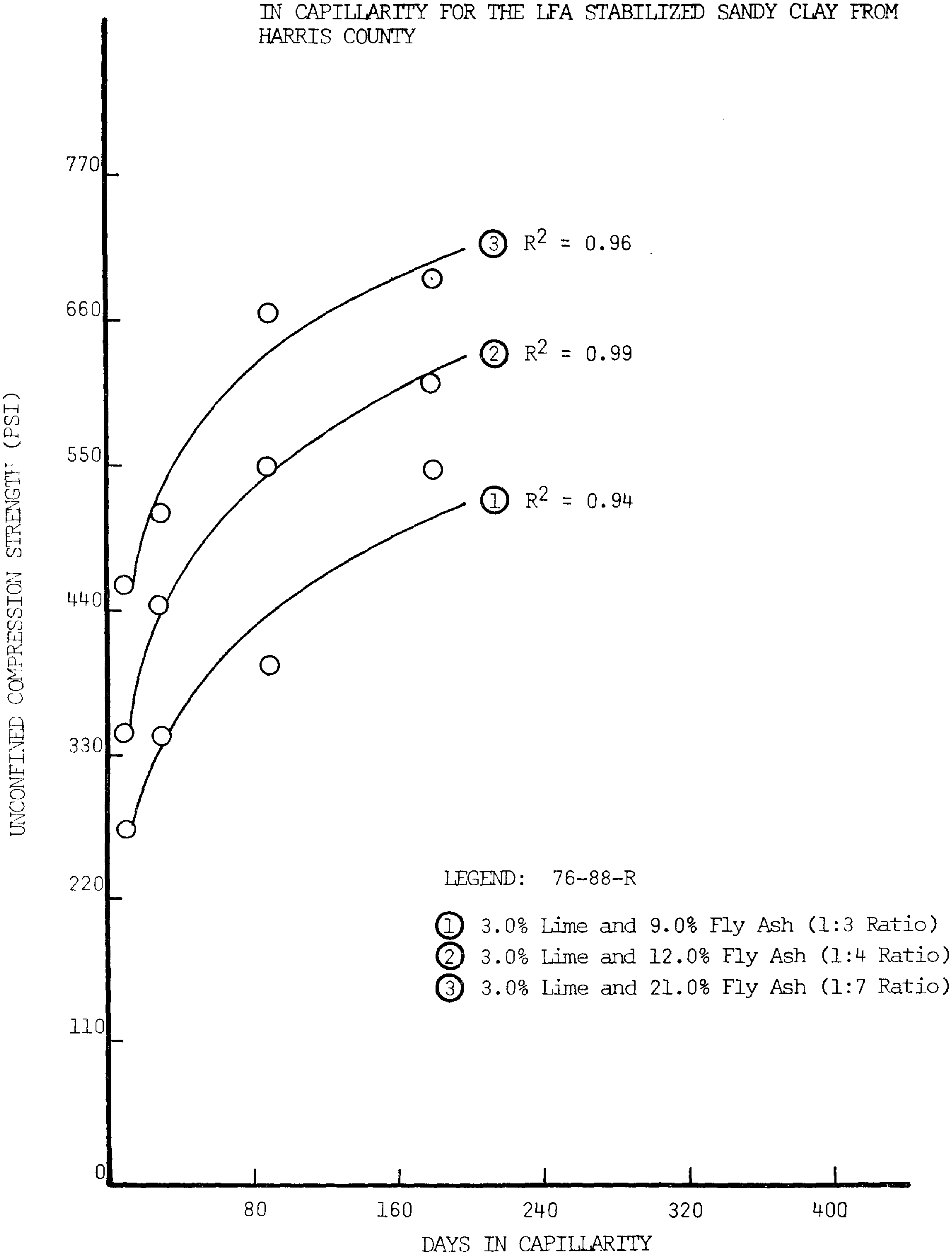
UNCONFINED COMPRESSION TEST

RESULTS ON LFA STABILIZED

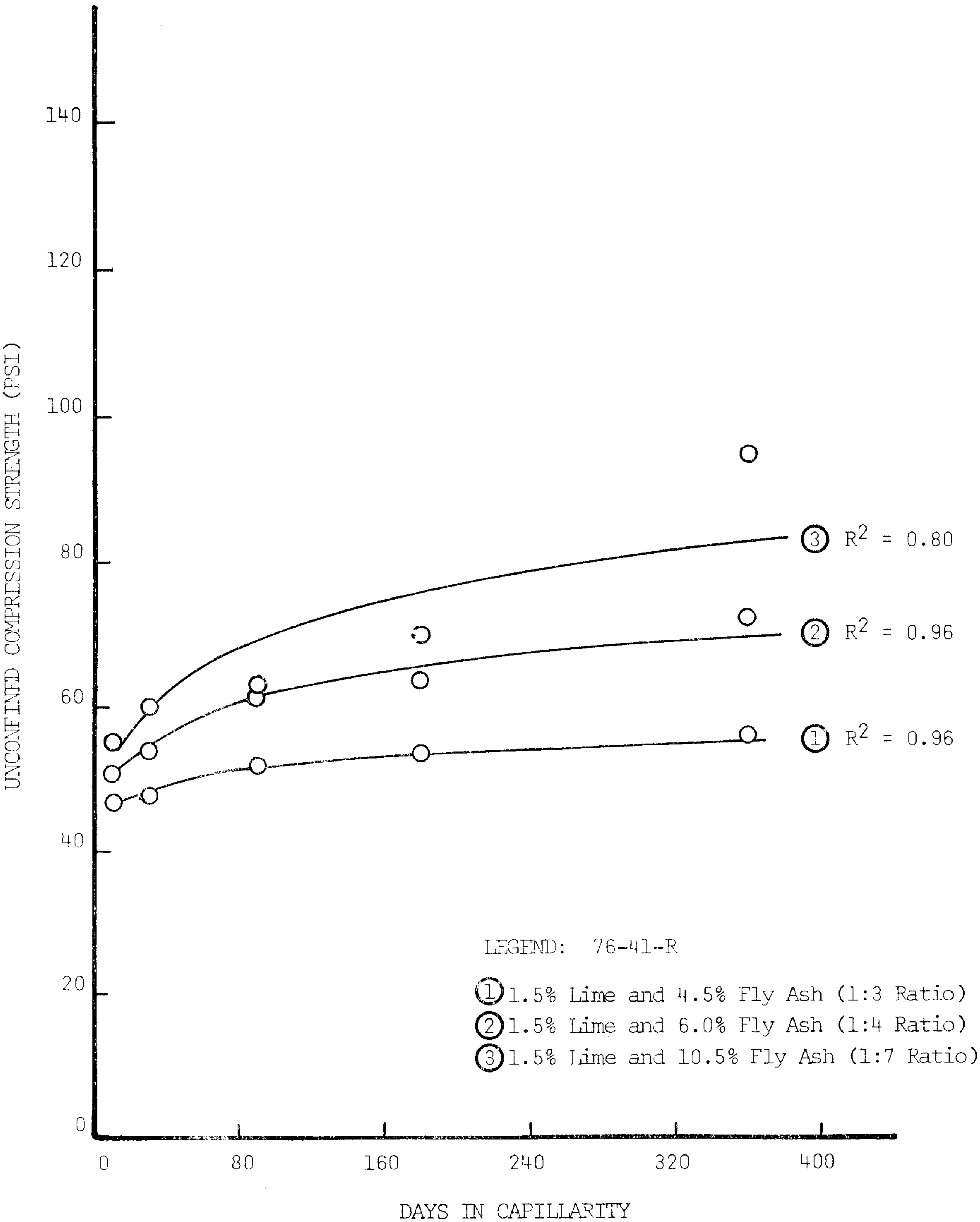
BASES AND SOILS


RELATION OF UNCONFINED COMPRESSION STRENGTH TO DAYS IN CAPILLARITY FOR THE LFA STABILIZED SANDY LOAM FROM TRAVIS COUNTY
③ R2 = 0.99
② R2 = 0.99
① R2 = 0.99
440
385
330
275
220
165
110
55
0
UNCONFINED COMPRESSION STRENGTH (PSI)
0
80
160
240
320
400
DAYS IN CAPILLARITY
LEGEND: 74-151-R
① 1.5% Lime and 4.5% Fly Ash (1:3 Ratio)
② 1.5% Lime and 6.0% Fly Ash (1:4 Ratio)
③ 1.5% Lime and 10.5% Fly Ash (1:7 Ratio)

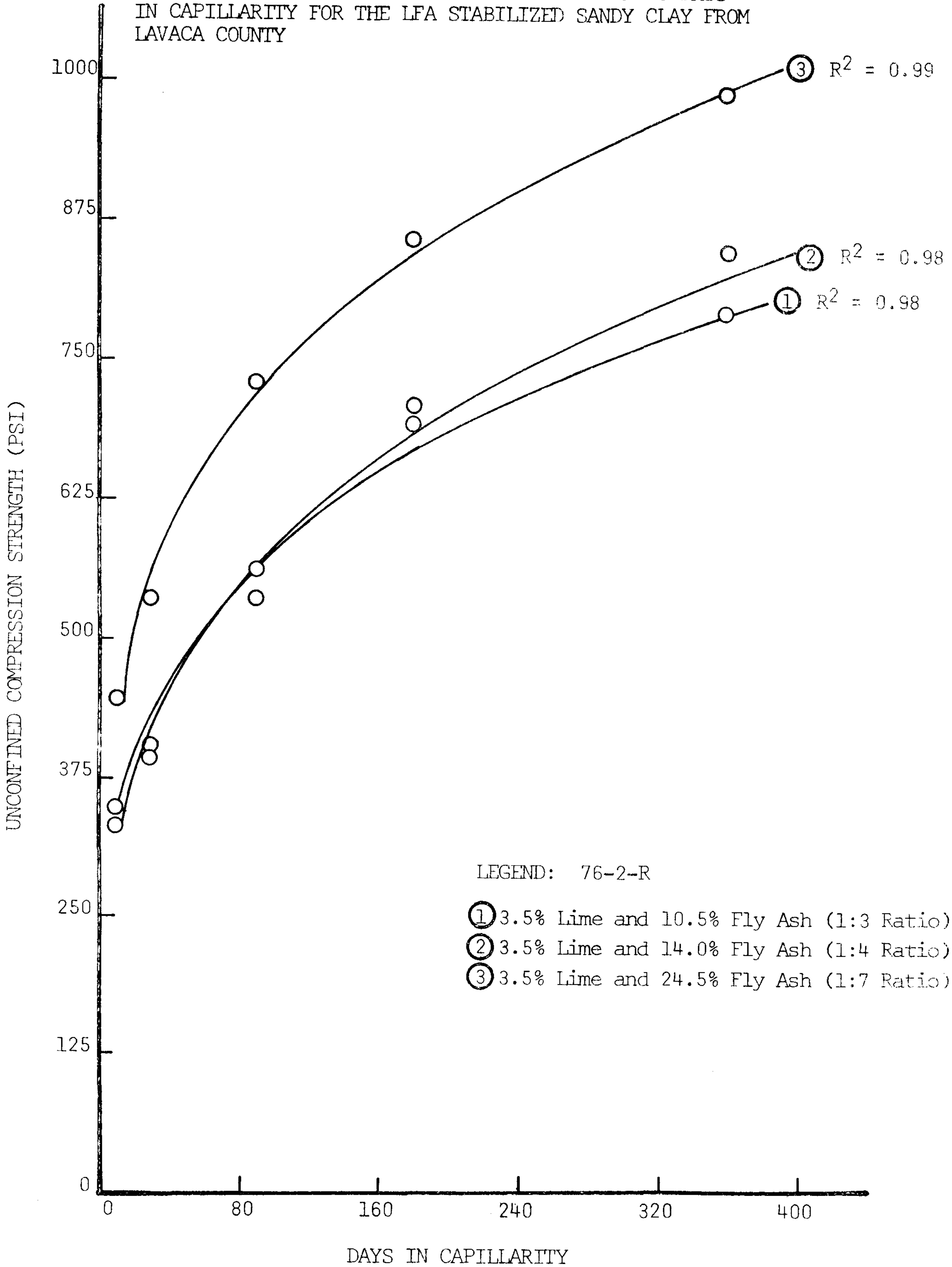
RELATION OF UNCONFINED COMPRESSION STRENGTH TO DAYS IN CAPILLARITY FOR THE LFA STABILIZED SANDY CLAY FROM HARRIS COUNTY



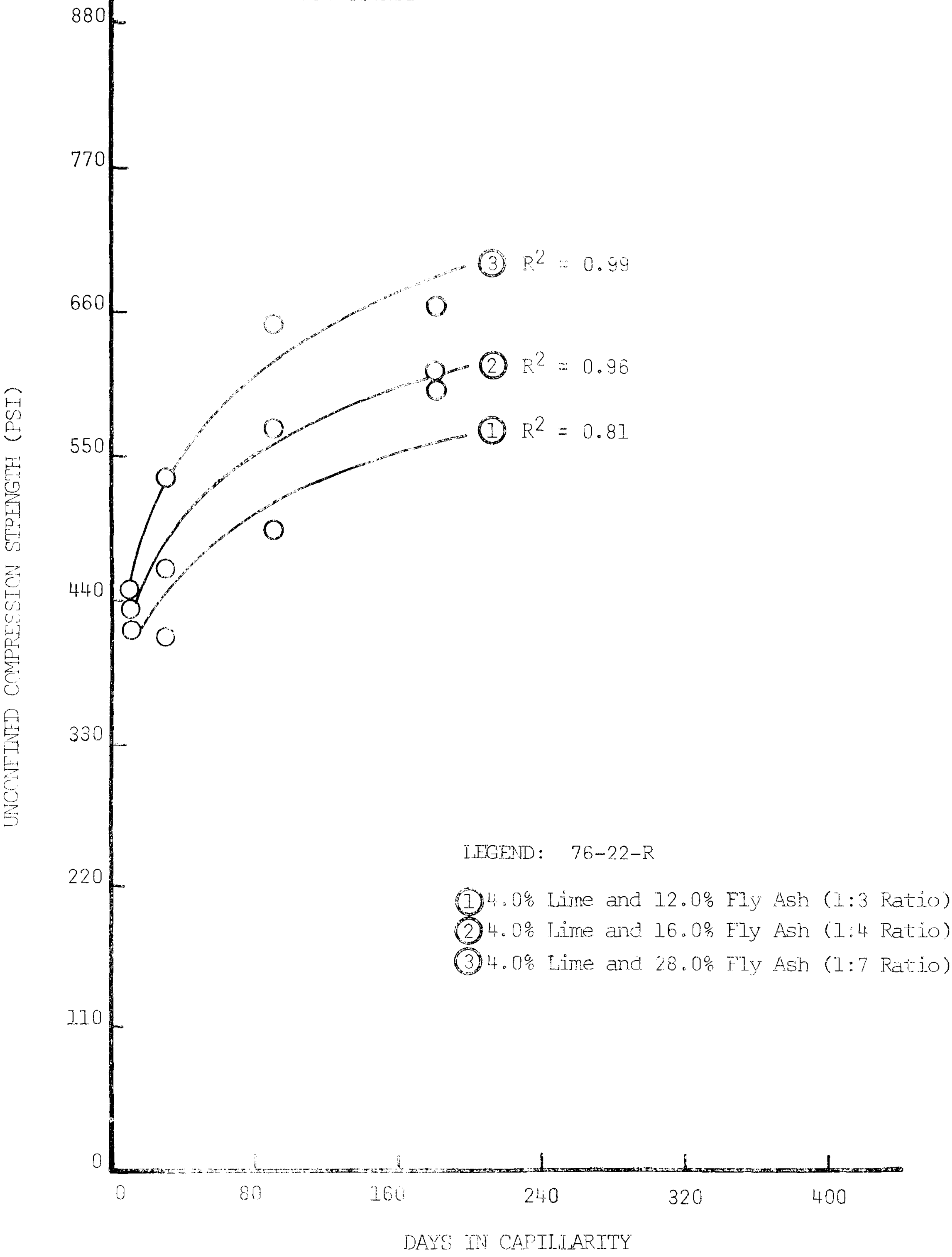
RELATION OF UNCONFINED COMPRESSION STRENGTH TO DAYS IN CAPILLARITY FOR THE LFA STABILIZED SANDY LOAM FROM SMITH COUNTY



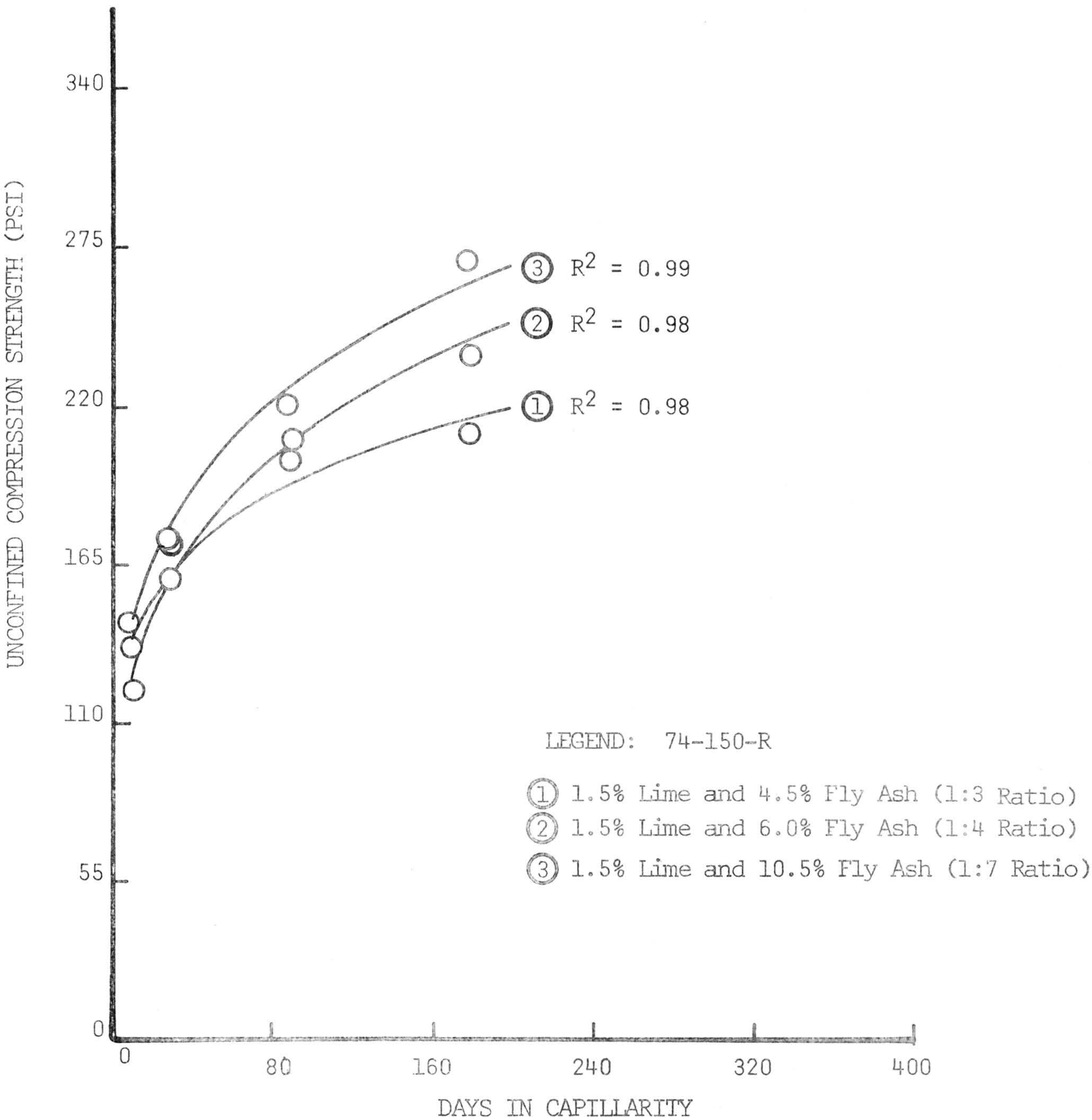
RELATION OF UNCONFINED COMPRESSION STRENGTH TO DAYS IN CAPILLARITY FOR THE LFA STABILIZED SANDY CLAY FROM LAVACA COUNTY



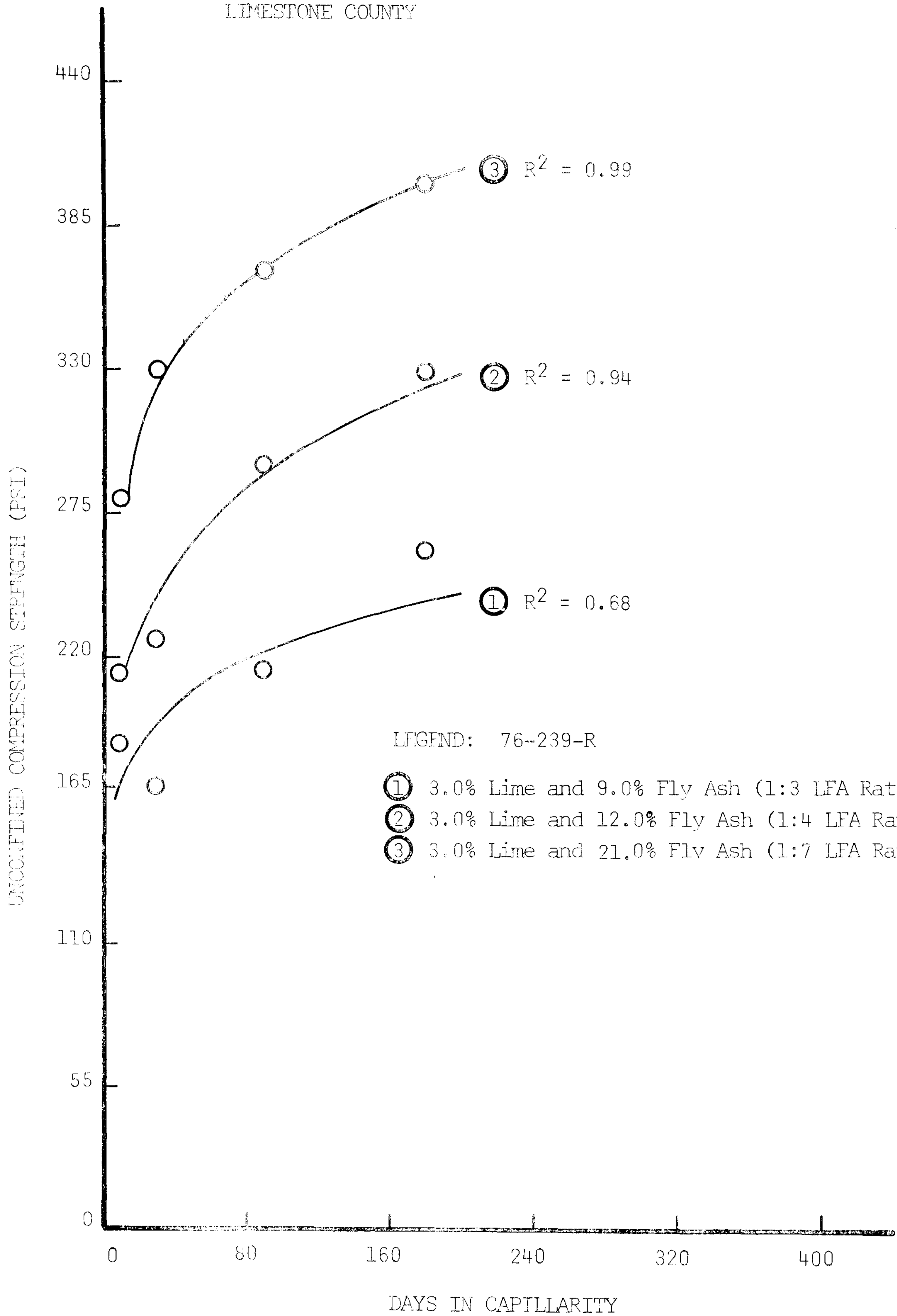
RELATION OF UNCONFINED COMPRESSION STRENGTH TO DAYS IN CAPILLARITY FOR THE LFA STABILIZED CLAY FROM WILLIAMSON COUNTY



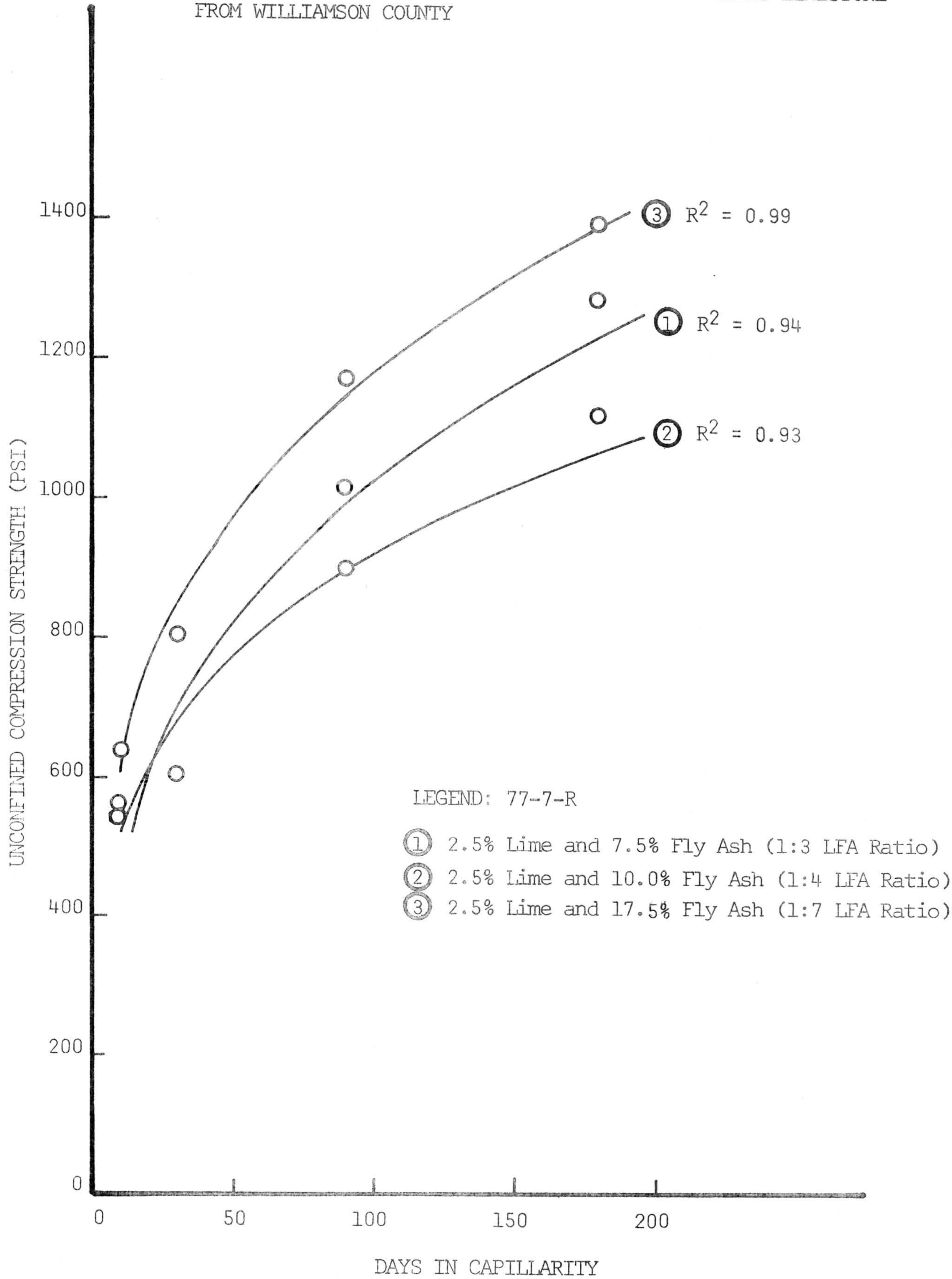
RELATION OF UNCONFINED COMPRESSION STRENGTH TO DAYS IN CAPILLARITY FOR THE LFA STABILIZED CLAYEY SAND FROM LEON COUNTY



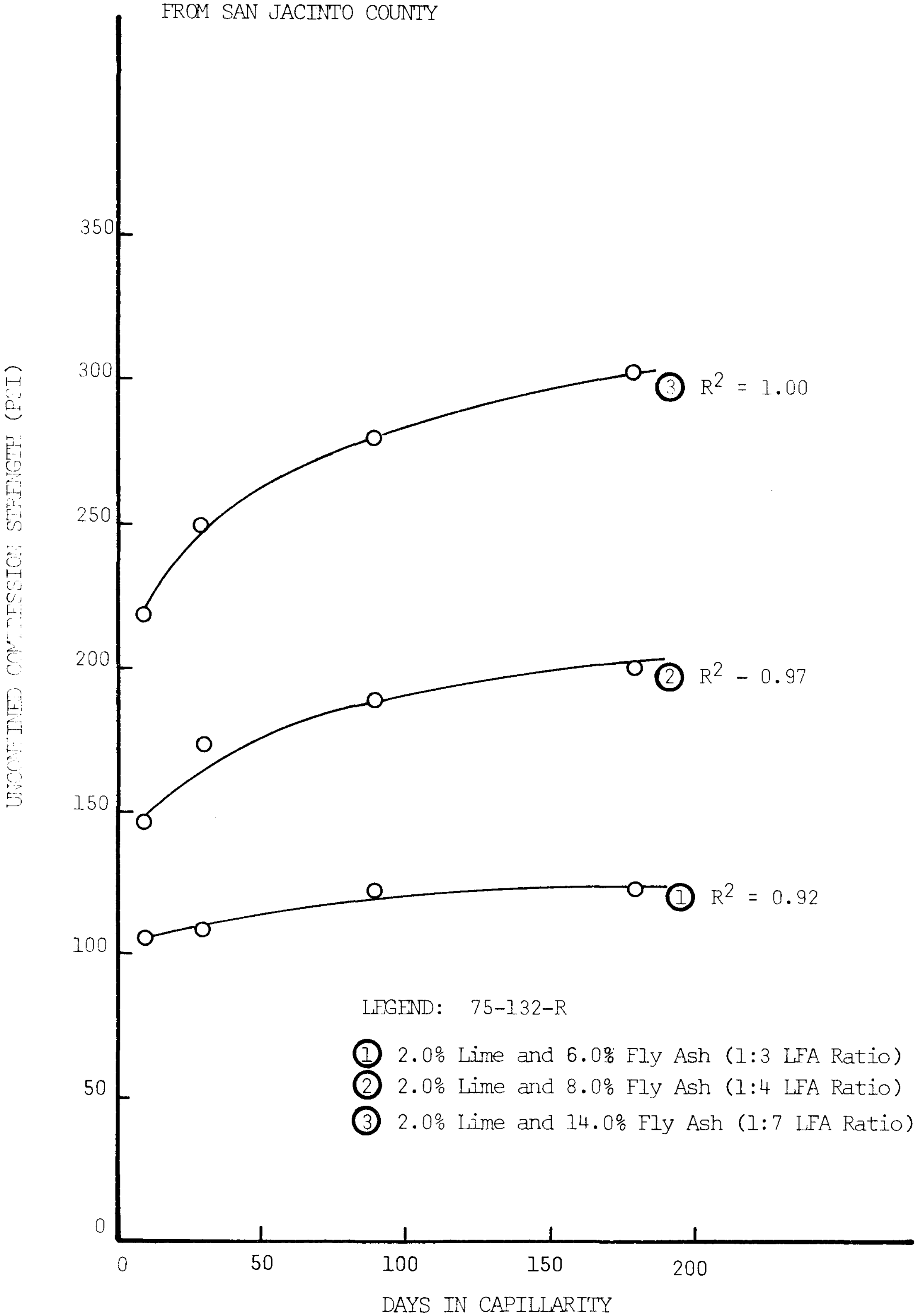
RELATION OF UNCONFINED COMPRESSION STRENGTH TO DAYS IN CAPILLARITY FOR THE LFA STABILIZED SANDY CLAY FROM LIMESTONE COUNTY



RELATION OF UNCONFINED COMPRESSION STRENGTH TO DAYS IN CAPILLARITY FOR THE LFA STABILIZED CRUSHED CLAYEY LIMESTONE FROM WILLIAMSON COUNTY



RELATION OF UNCONFINED COMPRESSION STRENGTH TO DAYS IN CAPILLARITY FOR THE LFA STABILIZED WILLIS IRON ORE GRAVEL FROM SAN JACINTO COUNTY



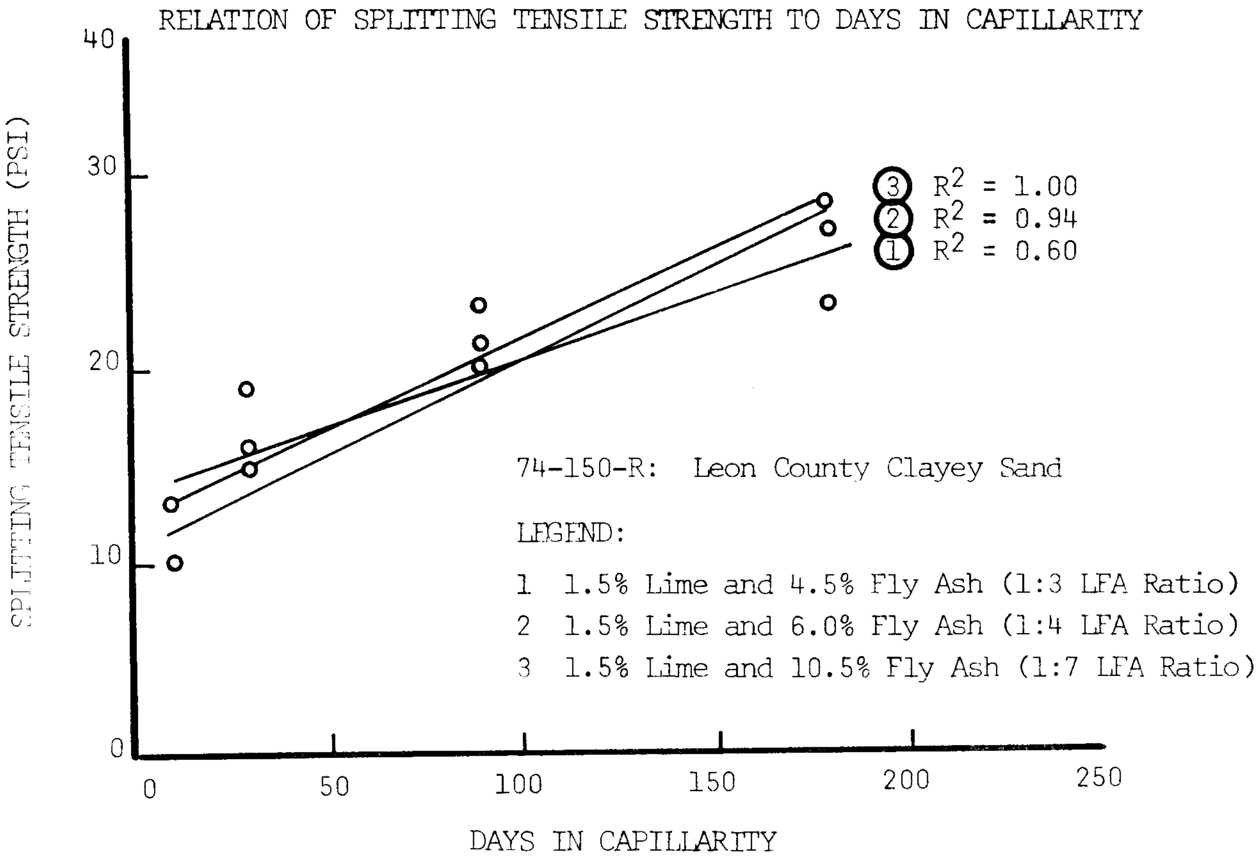
APPENDIX A, TAB.3

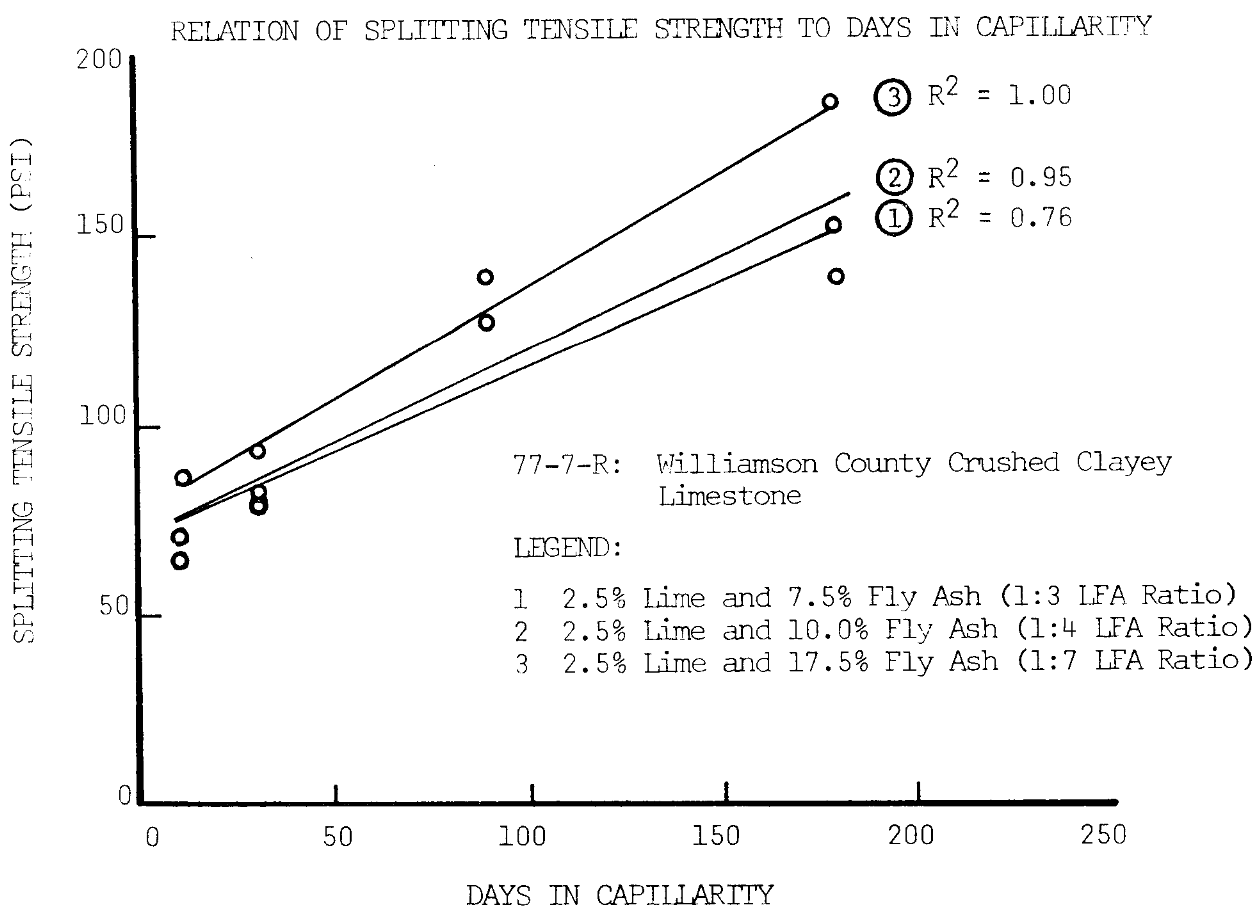
GRAPHICAL PRESENTATION OF

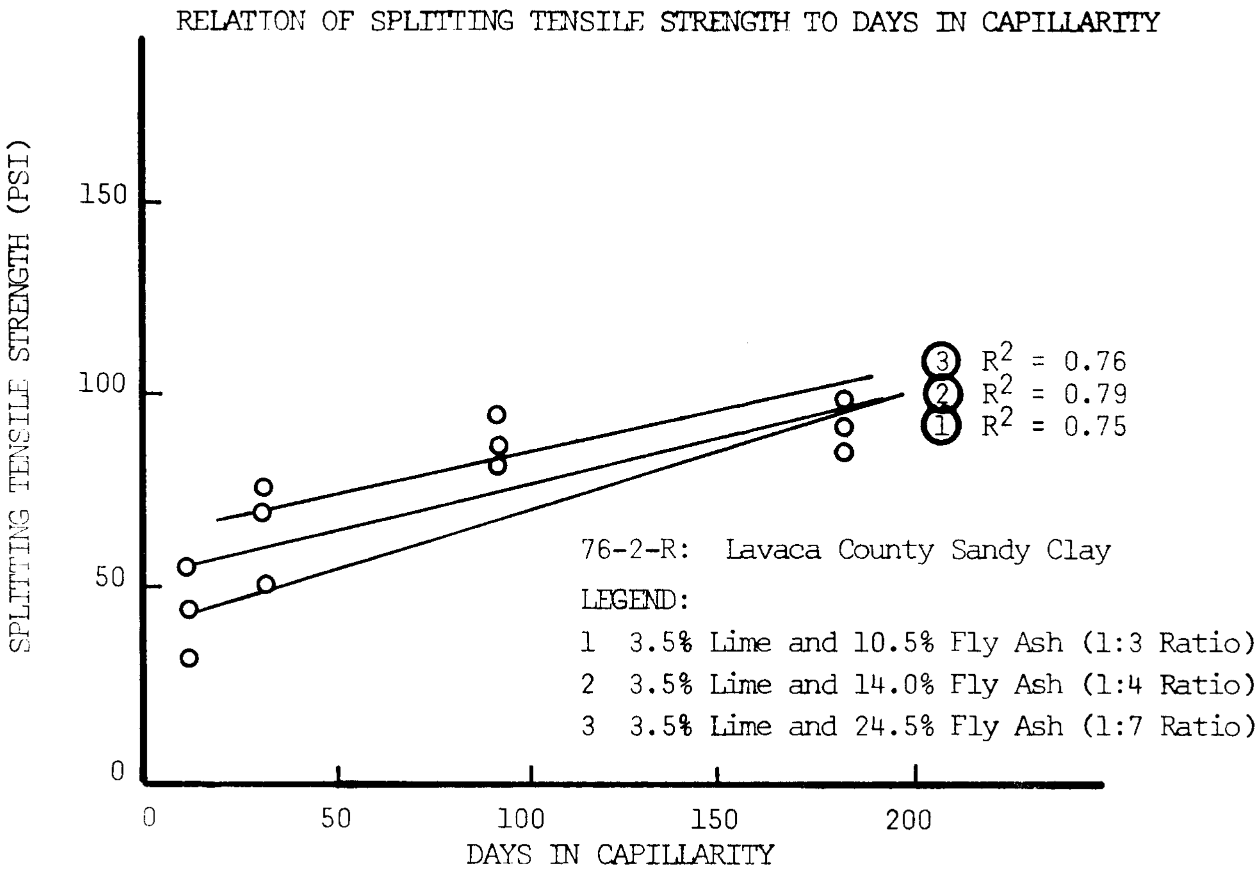
SPLITTING TENSILE TEST RESULTS

ON LFA STABILIZED BASES

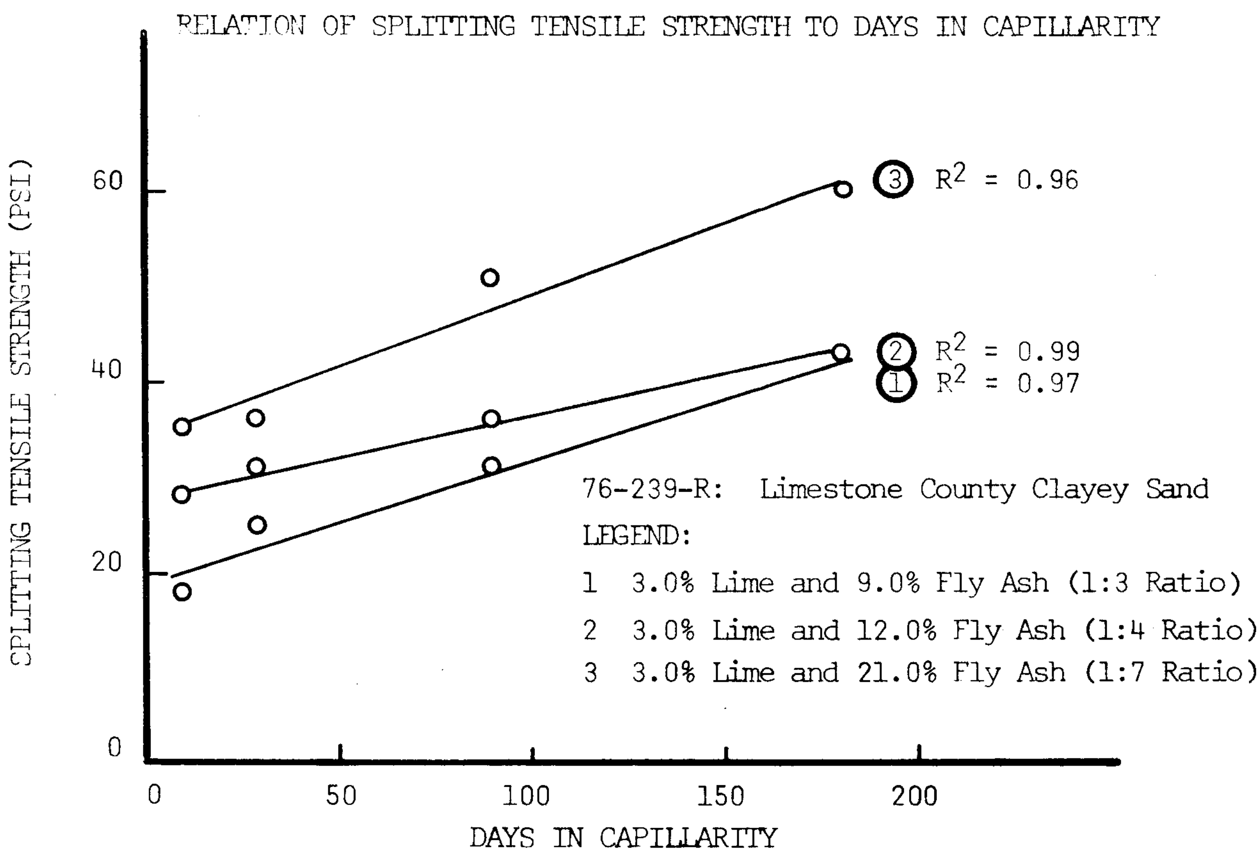
AND SOILS


RELATION OF SPLITTING TENSILE STRENGTH TO DAYS IN CAPILLARITY
SPLITTING TENSILE STRENGTH (PSI)
DAYS IN CAPILLARITY
0
10
20
30
40
0
50
100
150
200
250
3 R^2 = 1.00
2 R^2 = 0.94
1 R^2 = 0.60
74-150-R: Leon County Clayey Sand
LEGEND:
1 1.5% Lime and 4.5% Fly Ash (1:3 LFA Ratio)
2 1.5% Lime and 6.0% Fly Ash (1:4 LFA Ratio)
3 1.5% Lime and 10.5% Fly Ash (1:7 LFA Ratio)

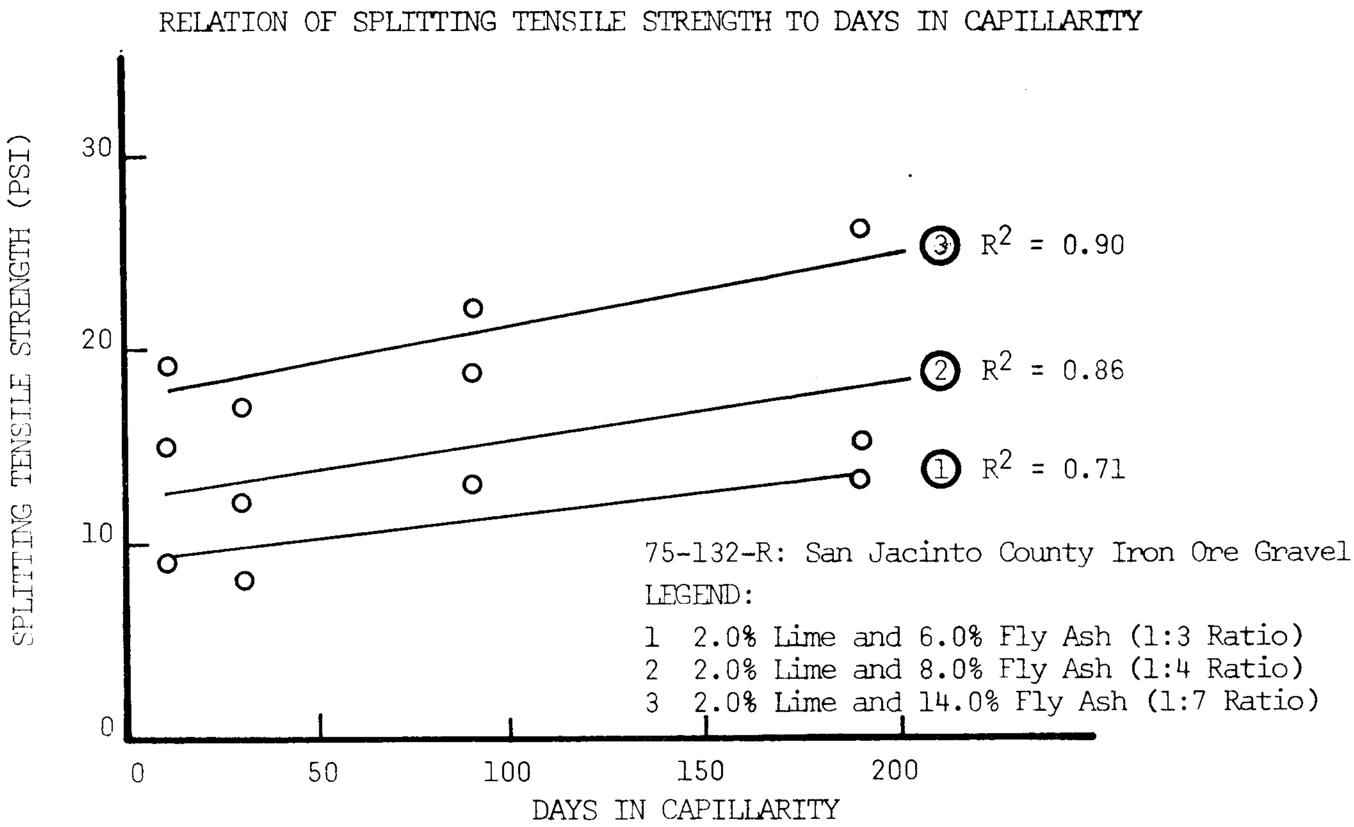

RELATION OF SPLITTING TENSILE STRENGTH TO DAYS IN CAPILLARITY
SPLITTING TENSILE STRENGTH (PSI)
DAYS IN CAPILLARITY
0
50
100
150
200
0
50
100
150
200
250
3 R^2 = 1.00
2 R^2 = 0.95
1 R^2 = 0.76
77-7-R: Williamson County Crushed Clayey Limestone
LEGEND:
1 2.5% Lime and 7.5% Fly Ash (1:3 LFA Ratio)
2 2.5% Lime and 10.0% Fly Ash (1:4 LFA Ratio)
3 2.5% Lime and 17.5% Fly Ash (1:7 LFA Ratio)

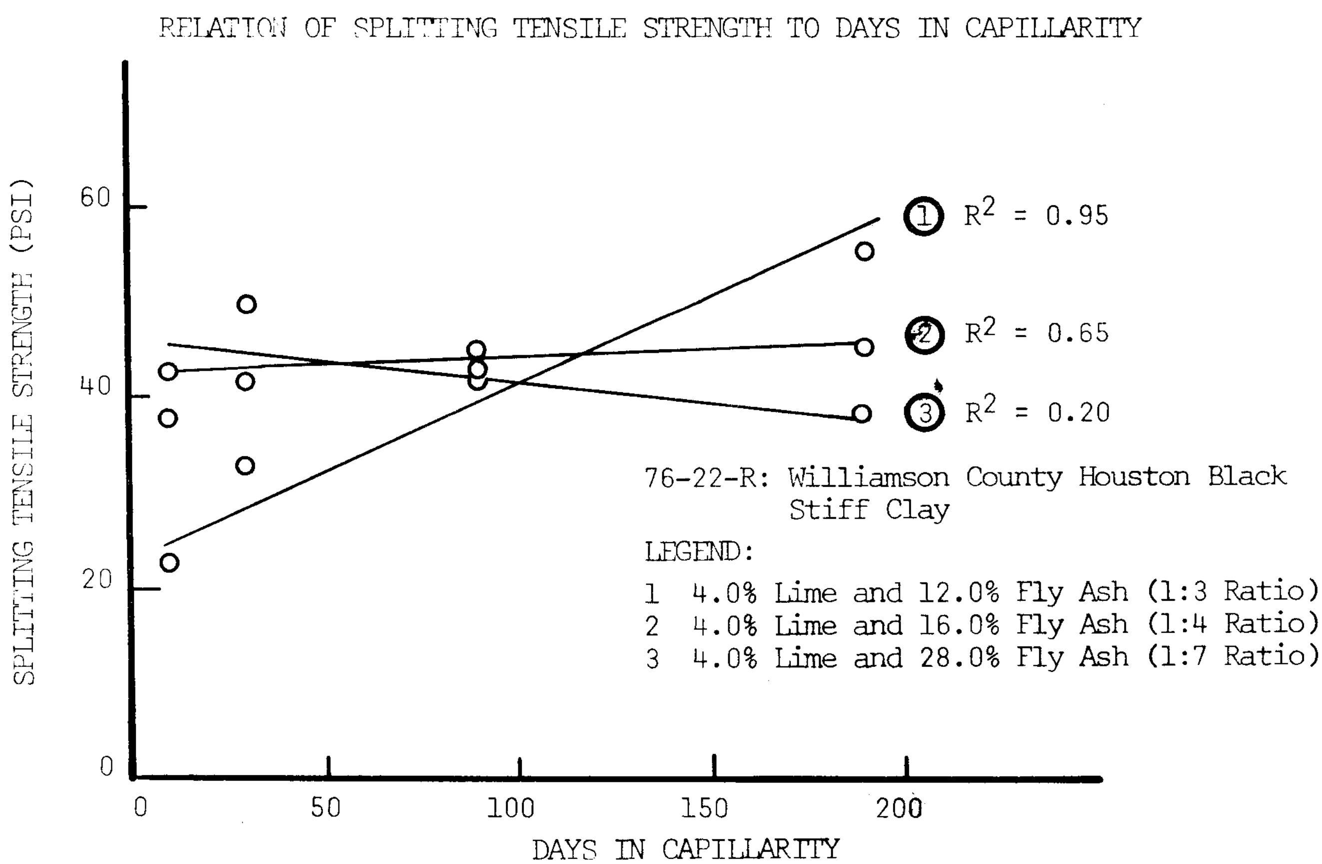


RELATION OF SPLITTING TENSILE STRENGTH TO DAYS IN CAPILLARITY
SPLITTING TENSILE STRENGTH (PSI)
150
100
50
0
0
50
100
150
200
DAYS IN CAPILLARITY
3 R2 = 0.76
2 R2 = 0.79
1 R2 = 0.75
76-2-R: Lavaca County Sandy Clay
LEGEND:
1 3.5% Lime and 10.5% Fly Ash (1:3 Ratio)
2 3.5% Lime and 14.0% Fly Ash (1:4 Ratio)
3 3.5% Lime and 24.5% Fly Ash (1:7 Ratio)

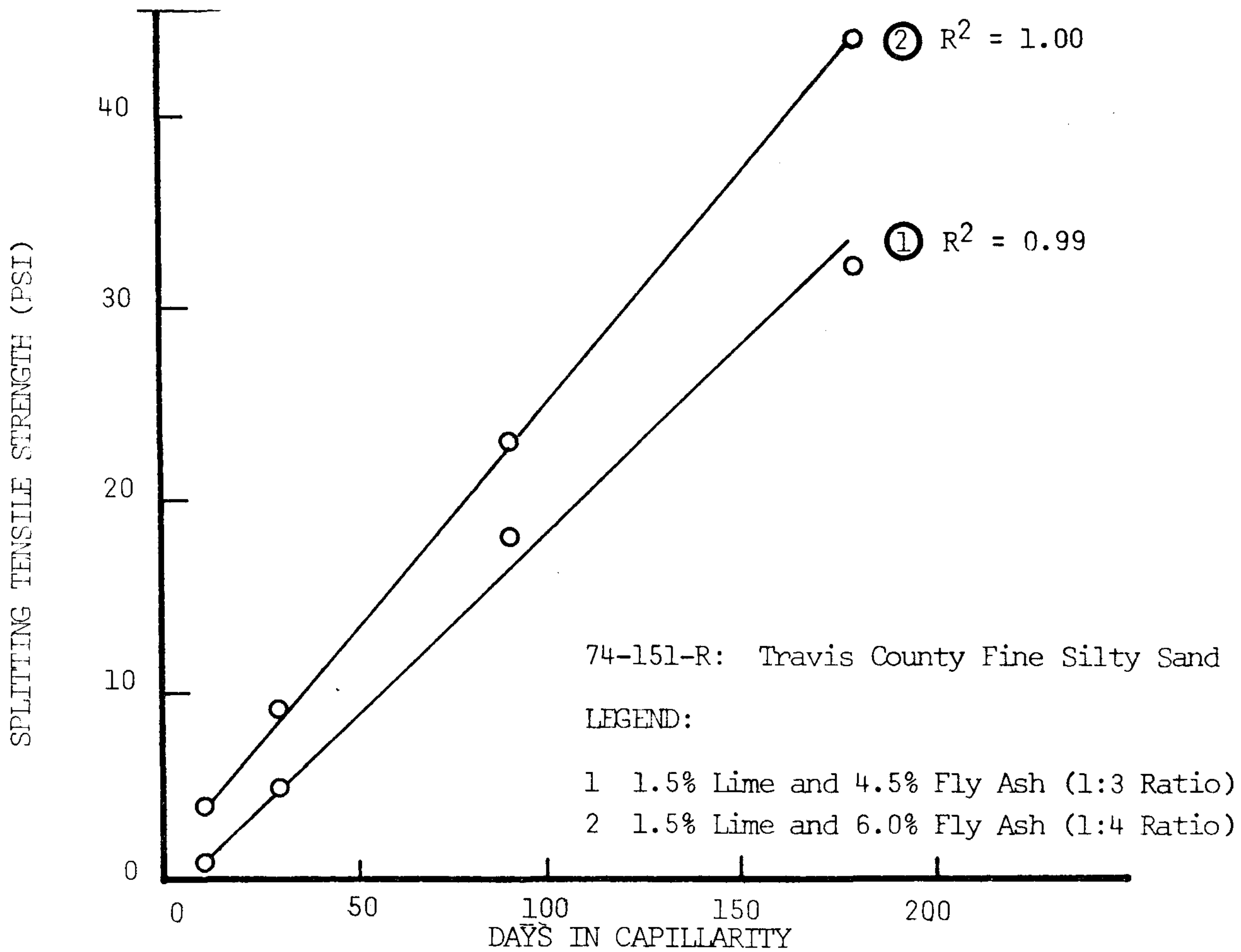


RELATION OF SPLITTING TENSILE STRENGTH TO DAYS IN CAPILLARITY
SPLITTING TENSILE STRENGTH (PSI)
60
40
20
0
0
50
100
150
200
DAYS IN CAPILLARITY
3 R2 = 0.96
2 R2 = 0.99
1 R2 = 0.97
76-239-R: Limestone County Clayey Sand
LEGEND:
1 3.0% Lime and 9.0% Fly Ash (1:3 Ratio)
2 3.0% Lime and 12.0% Fly Ash (1:4 Ratio)
3 3.0% Lime and 21.0% Fly Ash (1:7 Ratio)

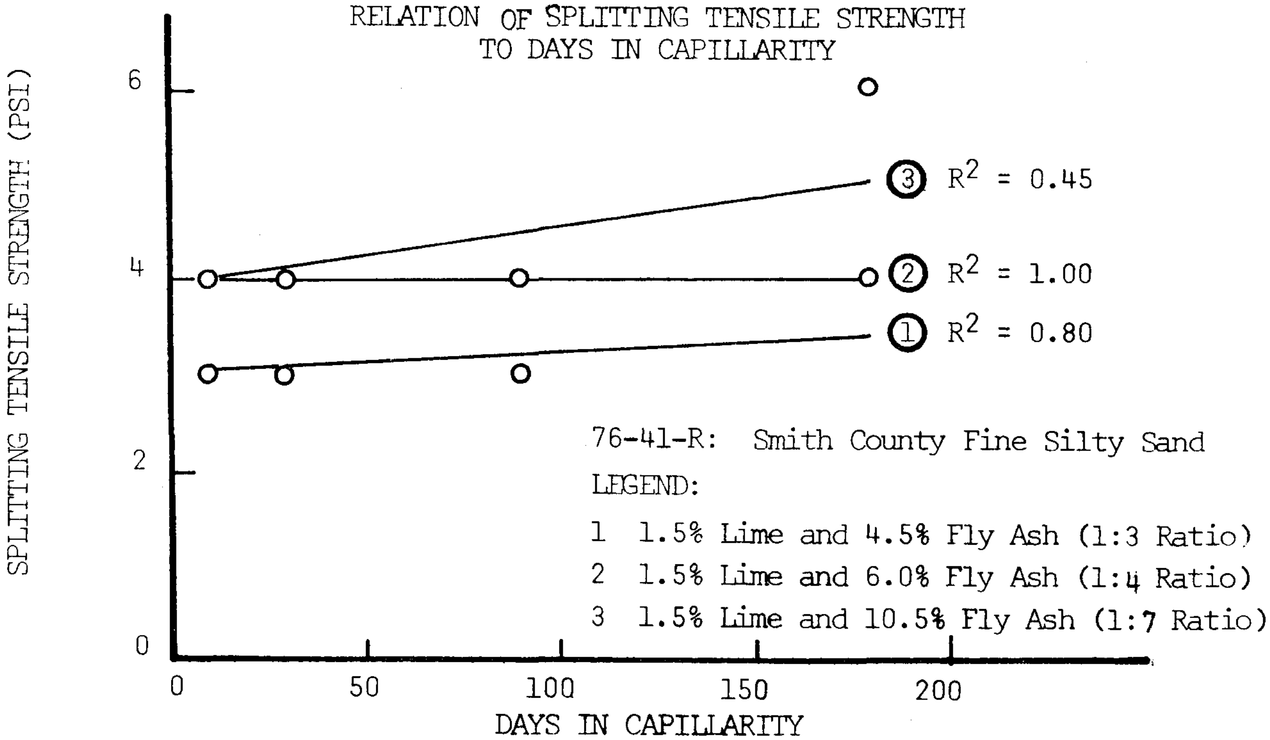

RELATION OF SPLITTING TENSILE STRENGTH TO DAYS IN CAPILLARITY
SPLITTING TENSILE STRENGTH (PSI)
30
20
10
0
0
50
100
150
200
DAYS IN CAPILLARITY
3 R2 = 0.90
2 R2 = 0.86
1 R2 = 0.71
75-132-R: San Jacinto County Iron Ore Gravel
LEGEND:
1 2.0% Lime and 6.0% Fly Ash (1:3 Ratio)
2 2.0% Lime and 8.0% Fly Ash (1:4 Ratio)
3 2.0% Lime and 14.0% Fly Ash (1:7 Ratio)


RELATION OF SPLITTING TENSILE STRENGTH TO DAYS IN CAPILLARITY
SPLITTING TENSILE STRENGTH (PSI)
60
40
20
0
0
50
100
150
200
DAYS IN CAPILLARITY
1 R2 = 0.95
2 R2 = 0.65
3 R2 = 0.20
76-22-R: Williamson County Houston Black Stiff Clay
LEGEND:
1 4.0% Lime and 12.0% Fly Ash (1:3 Ratio)
2 4.0% Lime and 16.0% Fly Ash (1:4 Ratio)
3 4.0% Lime and 28.0% Fly Ash (1:7 Ratio)

RELATION OF SPLITTING TENSILE STRENGTH
TO DAYS IN CAPILLARITY

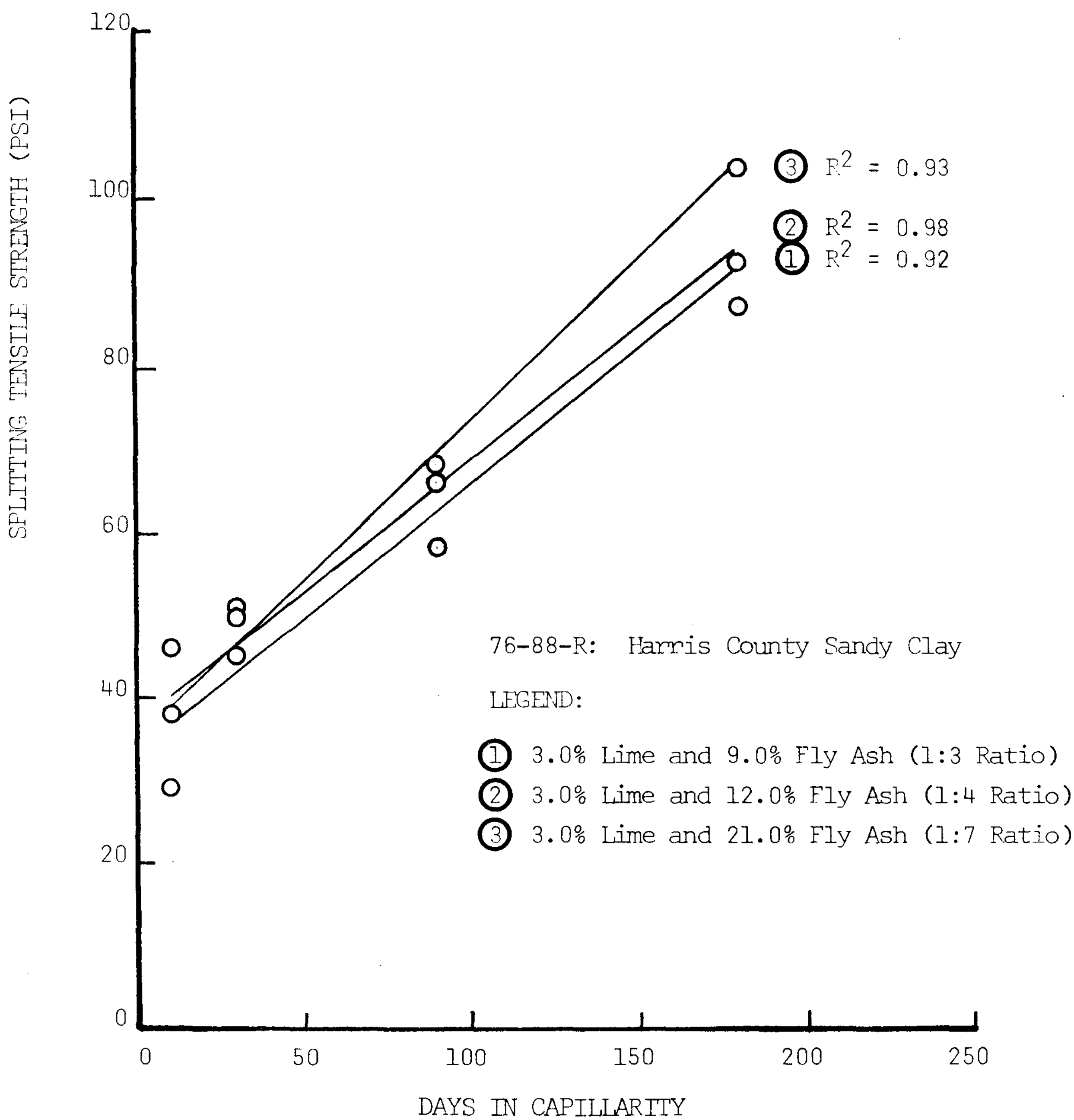


RELATION OF SPLITTING TENSILE STRENGTH
TO DAYS IN CAPILLARITY



RELATION OF SPLITTING TENSILE STRENGTH

TO DAYS IN CAPILLARITY



APPENDIX B

RECOMMENDED LABORATORY PROCEDURES FOR INVESTIGATING STRENGTH CHARACTERISTICS OF SOILS AND LIME-FLY ASH (LFA) OR FLY ASH (FA) MIXTURES

State Department of Highways and Public Transportation

Materials and Tests Division

FLY ASH COMPRESSIVE STRENGTH TEST METHODS

Scope

This method describes a procedure for determining the unconfined compressive strength as an index of the effectiveness of fly ash (FA) or lime-fly ash (LFA) treatment in imparting desirable properties to flexible base and subgrade materials.

Apparatus

The apparatus outlined in Test Methods Tex-101-E, Tex-113-E, Tex-117-E and Tex-126-E. A compression Testing Machine meeting the requirements of ASTM Designation D 1633-63 with a capacity of 60,000 pounds or equal. The Triaxial Screw Jack Press described in Test Method Tex-114-E may be used when anticipated strengths are not in excess of 400 psi.

Materials

1. A fresh supply of tested fly ash meeting the requirements of ASTM C 593.
2. A fresh supply of tested hydrated lime meeting the requirements of SDHPT 1972 Standard Specifications, Item 264.
3. The flexible base or soil to be stabilized.
4. Good quality potable tap water.

Test Record Forms

Use data forms similar to those shown in Test Method Tex-121-E.

Preparation of Sample

Select an adequate size representative sample of the material to be stabilized and prepare in accordance with Test Method Tex-101-E.

Procedure

1. Determining optimum moisture and density: Use the method described under Test Method Tex-113-E and determine the optimum moisture and maximum density for the FA and/or LFA mixtures. Using the soil constants, select the hydrated lime content from Figure 3, Test Method Tex-121-E. The amount of lime to use is a percentage based on the dry weight of the soil. Blend sufficient FA with the selected lime content to form a dry LFA ratio of 1:4 (1 part lime to 4 parts fly ash). In performing this part of the test, mix the LFA with the portion of material passing the No. 10 sieve. Wet the plus No. 10 portion with some or all of the weighed quantity of water (depending on how much plus No. 10 the sample contains) and stir and wet the aggregates thoroughly, Then add in the mixture of minus No. 10 material with LFA, mix thoroughly and compact each of the 4 layers with a compactive effort of 13.26 ft-lb/cu. in.

2. Compaction of the test specimens: Compact three specimens either 4 inches or 6 inches in diameter and 6 inches in height respectively at the optimum moisture and density found by using 4 layers and 13.26 ft-lb/cu in compactive effort. Other LFA ratios may be investigated using the optimum moisture determined from the 1:4 LFA ratio. These FA or LFA treated materials should be compacted as nearly identically as possible.

3. Curing Test Specimens.

   a. The test specimens with top and bottom porous stones in place are covered with a triaxial cell immediately after extruding from the forming mold. The specimens are then stored at room temperature for a period of 7 days.

   b. After this moist curing period, remove the cells and place the specimens in a dryer and dry at a temperature not to exceed 140 F for about 6 hours or until one-third to one-half of the molding moisture has been removed. All FA and LFA-treated soils are dried as given above even though a considerable amount of cracking may occur. Allow the specimens to cool to room temperature before continuing the test.

   c. Weigh, measure, and enclose the specimens in triaxial cells and subject them to capillarity for ten days. Use a constant lateral pressure of 1/2 psi to 1 psi depending upon the use of the material being tested.

4. Testing the Specimens: The specimens are removed from the moist room and prepared for testing in unconfined compression as outlined in Test Method Tex-117-E. A compression testing machine of adequate range and sensitivity will be used. Curing data is recorded on a form similar to Figure 2, Test Method Tex-121-E. If the second specimen tests within 10 percent of the first, the Engineer may elect to test the third specimen in indirect tension.

Calculations and Graphs

The calculations are similar to those made for Test Method Tex-117-E. A graph is normally prepared showing compressive strength versus percent stabilizer used.

Reporting of Test Results

The laboratory report should include, but is not necessarily limited to the following:

1. Show the soil constants on Form 391.
2. Show molding, curing, swell, strain and strength test data on a form similar to Figure 15, Test Method Tex-117-E.
3. Plot strength graph if applicable.

General Testing Notes

1. Store hydrated lime in an airtight container to ensure a fresh supply.

2. Wetted stabilized materials taken from the roadway during construction should be prepared for testing without drying back as required by Test Method Tex-101-E. The Engineer will select the method of sample preparation best suited for construction control. The desired intent is to have the capability of weighing identical samples for strength and density control specifications. The sample may have moisture added and remixed or removed with a fan while stirring for developing compaction curves.

3. The Engineer may elect to use a 4.0-inch by 6.5-inch high mold ± 0.02 inch when investigating fine grained materials containing zero percent retained on the No. 4 (4.75 mm) sieve.

4. The number of blows and height of drop must be calculated when changing mold size to maintain a compactive effort of 13.26 ft-lb/cu in. on each of the 4 layers.

5. The Engineer may select and specify other conditioning procedures for construction control purposes. The District laboratory should develop design strength data for these other conditioning procedures. In any event, the curing and conditioning procedures shall be given in detail in the report.

General Design Notes

1. When water, lime, fly ash and material have been brought together during construction, the mixture should receive final mixing and compaction during that same working day.

2. Lime contents less than 2.0 percent are not recommended due to difficulty in obtaining distribution under construction conditions.

3. Fly ash or lime-fly ash stabilized soils are not recommended at this time as final base courses on primary highways because of limited performance records.

4. Unconfined compressive strengths of at least 100 psi are suggested as adequate for fly ash or lime-fly ash stabilized subbase soils cured at room temperature and subjected to 10 days capillarity.

5. Unconfined compressive strengths for fly ash or lime-fly ash base courses should approach the strength requirements of soil cement.

6. Lime-fly ash stabilized base courses will perform as semirigid pavements. The Engineer should not specify this type of pavement design on a soft foundation where relatively large deflections are likely to occur.

7. It is intended that field density control shall be based on testing road mixed samples in accordance with Test Method Tex-114-E. It is suggested that a minimum of 95 percent of compaction ratio density be obtained for both subgrade and base course stabilized with fly ash or lime-fly ash.

8. A density control specification is recommended for this type of stabilization.

9. Provisions should be made in the contract to control dusting of fly ash and lime.

10. It is recommended that lime-fly ash base stabilization receive an asphaltic surface course from base crown to base crown to reduce erosion along the pavement edge.

APPENDIX B, TAB. 2

PICTORIAL PRESENTATION OF LABORATORY

PROCEDURE FOR LFA STABILIZATION

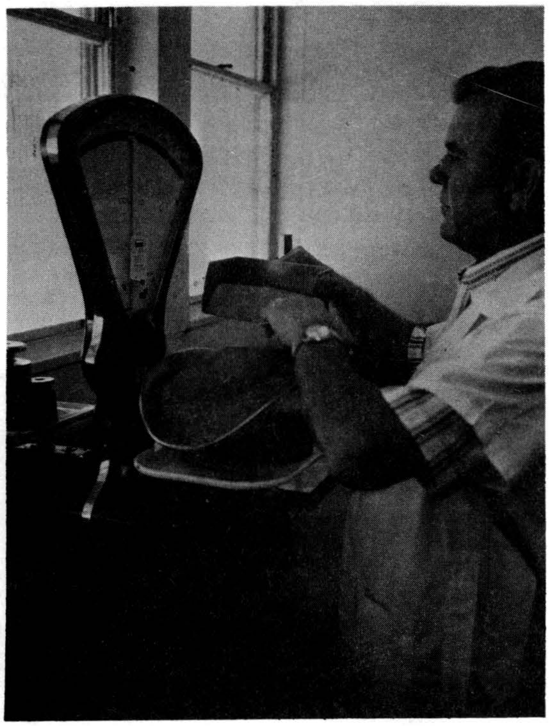


Figure 1. Proportioning the material for LFA stabilization.

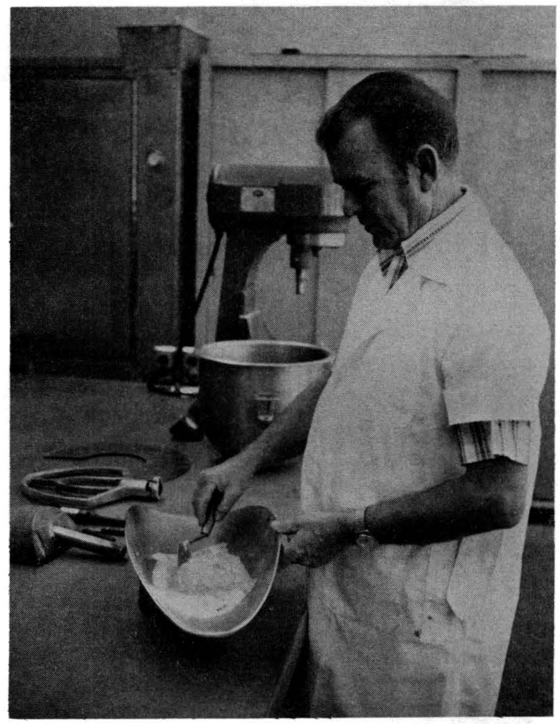


Figure 2. Dry blending the lime and fly ash prior to adding the material and molding water.

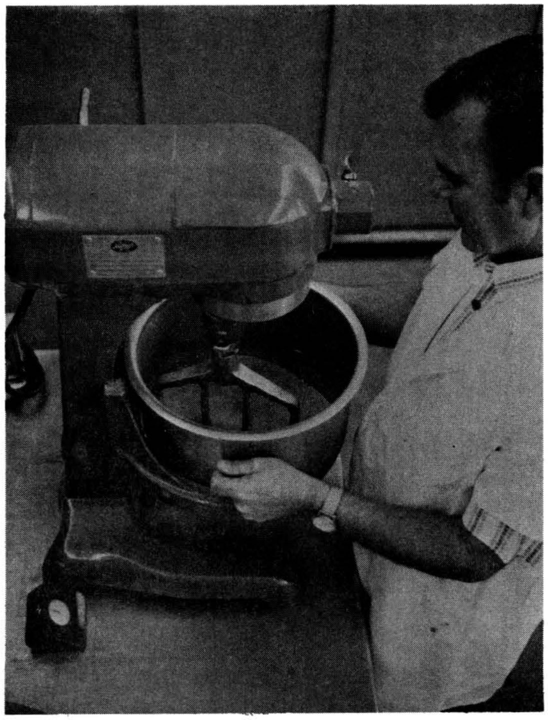


Figure 3. Dry blending the soil, lime and fly ash prior to final mixing with water.

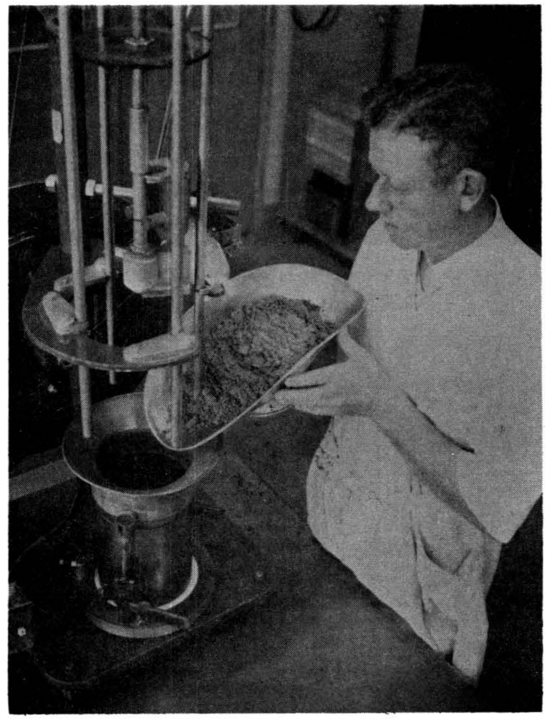


Figure 4. Adding the mixed material to the Rainhart Compactor.

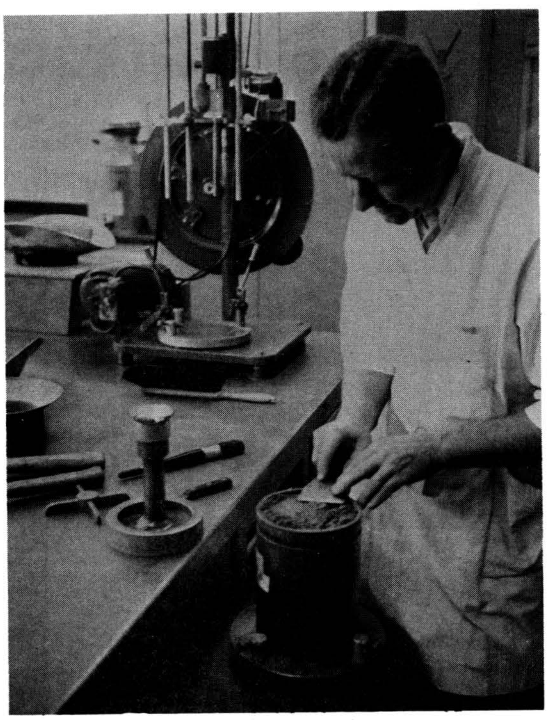


Figure 5. Initial leveling of the compacted LFA specimen.

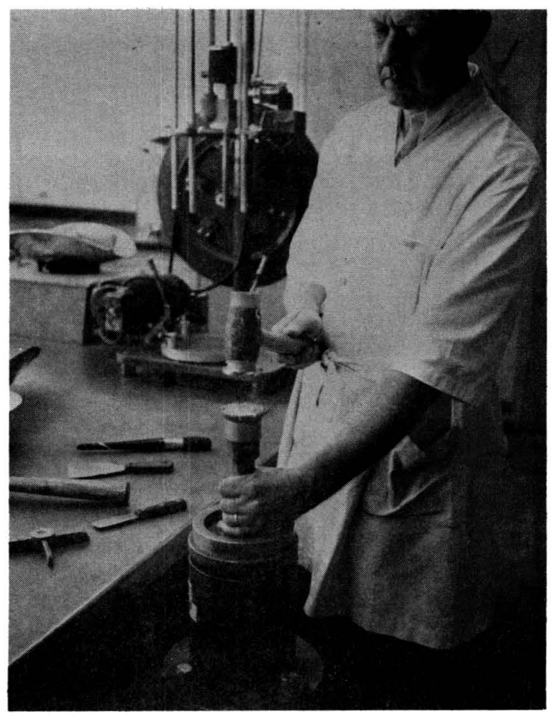


Figure 6. Final finishing procedure in leveling the compacted LFA specimen.

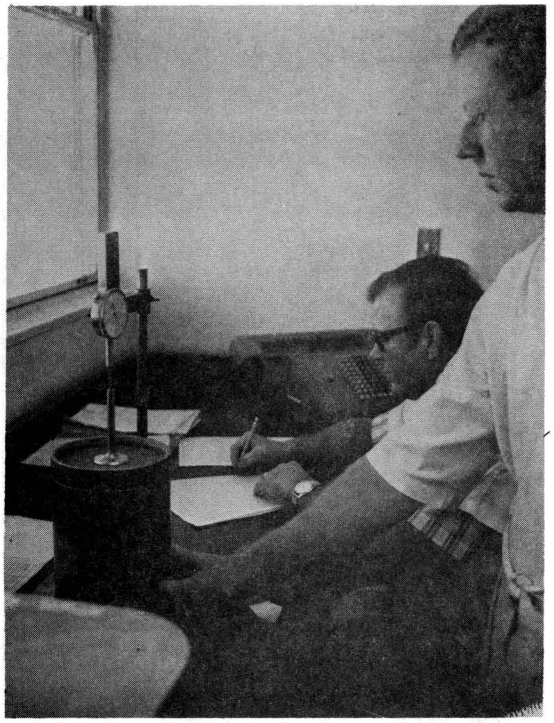


Figure 7. Obtaining height measurement for density calculations on the compacted LFA specimen.

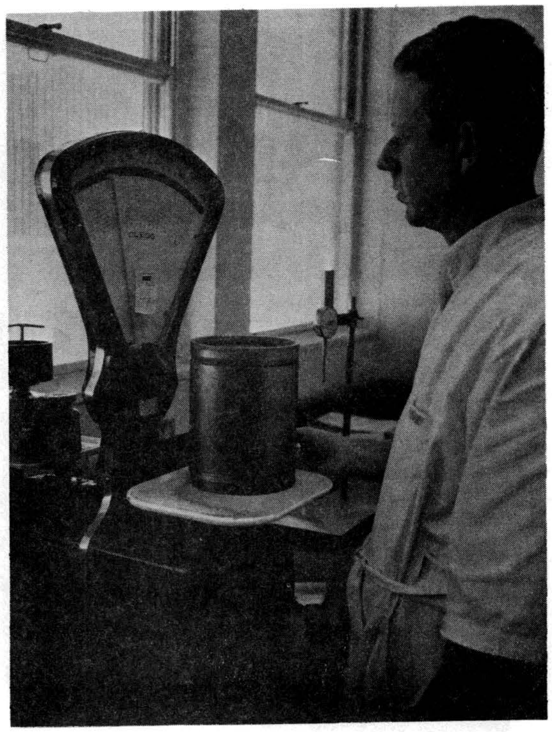


Figure 8. Obtaining weight measurement for density calculations on the compacted LFA specimen.

Figure 9. Extruding the LFA specimen from the 6 inch by 8 inch compaction mold.

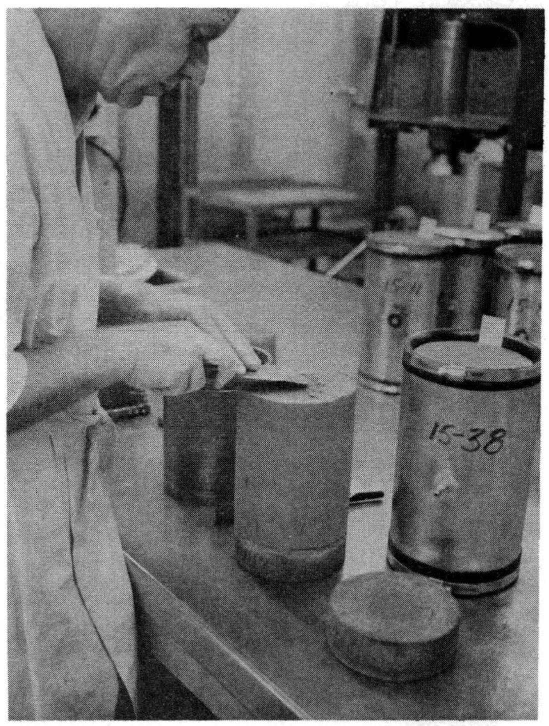


Figure 10. Adding the loose material created in the extruding process back to the compacted LFA specimen.

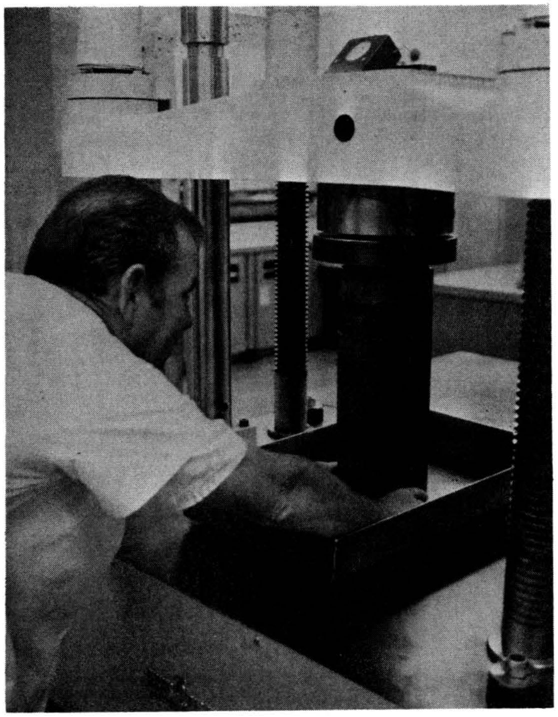


Figure 11. Preparing an LFA stabilized specimen for unconfined compression on the Tinius Olsen Machine. The motorized gyratory and testing press shown in Figure 12 may be used for unconfined compression testing on LFA mixtures with strength values less than 800 psi.

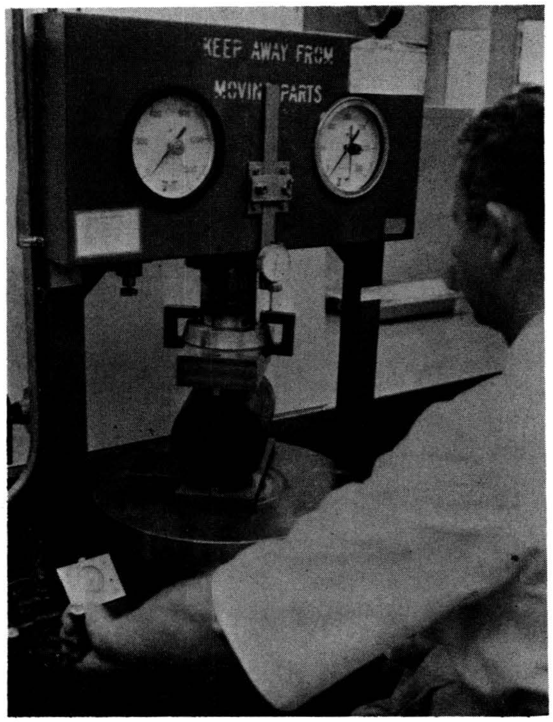


Figure 12. Positioning a cured LFA specimen for indirect or splitting tensile testing.

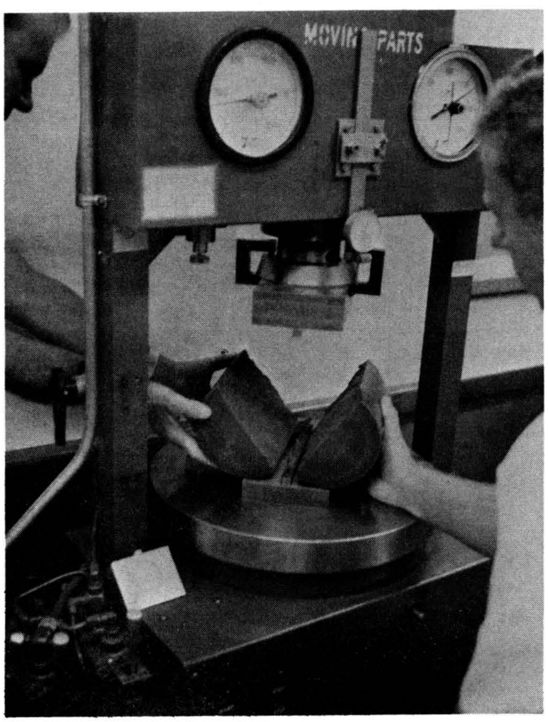


Figure 13. Appearance of the LFA specimen after completion of the splitting tensile test. This test has broken across aggregates in LFA mixtures made with crushed stone.

APPENDIX C

RECOMMENDED SPECIAL SPECIFICATION

FOR

LIME-FLY ASH (LFA) TREATMENT FOR MATERIALS IN PLACE

STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

SPECIAL SPECIFICATION

ITEM 2048

LIME-FLY ASH (LFA) TREATMENT FOR MATERIALS IN PLACE

1. DESCRIPTION. This Item shall consist of treating the subgrade, existing subbase or existing base by the pulverizing, addition of lime and fly ash, mixing and compacting the mixed material to the required density. This Item applies to natural ground, embankment, or existing pavement structure and shall be constructed as specified herein and in conformity with the typical sections, lines and grades as shown on the plans or as established by the Engineer.

2. MATERIALS.

(1) Lime. Lime shall meet the requirements of the Item, "Hydrated Lime and Lime Slurry," for the type of lime specified.

When Type B, Commercial Lime Slurry is specified, the Contractor shall select, prior to construction, the grade to be used and shall notify the Engineer in writing before changing from one grade to another.

(2) Fly Ash. Fly ash shall meet ASTM Specification C 593, Section 3.2, when sampled and tested in accordance with Sections 4, 6 and 8, unless otherwise shown on the plans. In any event, the water-soluble fraction shall not be determined.

(3) Water. Water shall meet the requirements of water for the Item, "Concrete Pavements."

(4) Bituminous Material. Bituminous material, if specified for curing, shall meet the requirements of bituminous material for the Item, "Asphalts, Oils and Emulsions."

(5) If the minimum design strength or percent of LFA to be used for the treated subgrade, existing subbase or existing base is specified, it will be determined by preliminary tests performed in accordance with Test Method Tex-127-E.

3. EQUIPMENT.

(1) The machinery, tools and equipment necessary for proper prosecution of the work shall be on the project and approved by the Engineer prior to the beginning of construction operations.

All machinery, tools and equipment used shall be maintained in a satisfactory and workmanlike manner.

(2) Hydrated lime and fly ash shall be stored and handled in closed weatherproof containers until immediately before distribution on the road.

If storage bins are used, they shall be completely enclosed. Materials in bags shall be stored in weatherproof buildings with adequate protection from ground dampness.

(3) If lime and/or fly ash is furnished in trucks, each truck shall have the weight of lime and fly ash certified on public scales or the Contractor shall place a set of standard platform truck scales or hopper scales at a location approved by the Engineer.

Scales shall conform to the requirements of the Item "Weighing and Measuring Equipment."

(4) If lime and/or fly ash is furnished in bags, each bag shall bear the manufacturer's certified weight. Bags varying more than 5 percent from that weight may be rejected and the average weight of bags in any shipment, as shown by weighing 50 bags taken at random, shall not be less than the manufacturer's certified weight.

4. CONSTRUCTION METHODS.

(1) General. It is the primary requirement of this specification to secure a completed course of treated material containing a uniform LFA mixture free from loose or segregated areas, of uniform density and moisture content, well bound for its full depth and with a smooth surface suitable for placing subsequent courses. It shall be the responsibility of the Contractor to regulate the sequence of his work, to process a sufficient quantity of material to provide full depth as shown on plans, to use the proper amounts of lime and fly ash, maintain the work and rework the courses as necessary to meet the above requirements.

(2) Preparation of Roadbed. Before other construction operations are begun, the roadbed shall be graded and shaped as required to construct the LFA treatment for materials in place in conformance with the lines, grades, thickness and typical cross section shown on the plans. Unsuitable soil or material shall be removed and replaced with acceptable material.

The subgrade shall be firm and able to support without displacement, the construction equipment and the compaction hereinafter specified. Soft or yielding subgrade shall be corrected and made stable by scarifying, adding lime and/or fly ash, and compacting until it is of uniform stability.

If the Contractor elects to use a cutting and pulverizing machine that will remove the subgrade material accurately to the secondary grade and pulverize the material at the same time, he will not be required to expose the secondary grade nor windrow the material. However, the Contractor shall be required to roll the subgrade, as directed by the Engineer, before using the pulverizing machine and correct any soft areas that this rolling may reveal. This method will be permitted only where a machine is provided which will insure that the material is cut uniformly to the proper depth and which has cutters that will plane the secondary grade to a smooth surface over the entire width of the cut. The machine shall be of such design that a visible indication is given at all times that the machine is cutting to the proper depth.

(3) Application. Lime shall be spread only on that area where the first mixing operation can be completed during the same working day.

The application and mixing of lime with the material shall be accomplished by the methods hereinafter described as "Dry Placing" or "Slurry Placing." When Type A, Hydrated Lime, is specified, the Contractor may use either method.

(a) Dry Placing. The lime shall be spread by an approved spreader or by bag distribution at the rates shown on the plans or as directed by the Engineer.

The lime and fly ash shall be distributed at a uniform rate and in such manner as to reduce the scattering of lime and fly ash by wind to a minimum. Lime and fly ash shall not be applied when wind conditions, in the opinion of the Engineer, are such that blowing lime and fly ash becomes objectionable to traffic or adjacent property owners. A motor grader shall not be used to spread the lime or fly ash.

The materials shall be sprinkled as directed by the Engineer, until the proper moisture content has been secured. However, initial mixing after the addition of lime or fly ash will be accomplished dry or with a minimum of water to prevent lime and/or fly ash balls.

(b) Slurry Placing. The lime shall be mixed with water in vehicles with approved distributors and applied as a thin water suspension or slurry.

Type B, Commercial Lime Slurry, shall be applied with a lime percentage not less than that applicable for the grade used. The distribution of lime at the rates shown on the plans or as directed by the Engineer shall be attained by successive passes over a measured section of roadway until the proper moisture and lime content has been secured. The distributor vehicle shall be equipped with an agitator which will keep the lime and water in a uniform mixture.

The fly ash may be placed in either the dry or slurry form under this method of application.

(4) Mixing. The mixing procedure shall be the same for "Dry Placing" or "Slurry Placing" as hereinafter described.

(a) First Mixing. The material and lime shall be thoroughly mixed by approved road mixers or other approved equipment, and the mixing continued until, in the opinion of the Engineer, a homogeneous, friable mixture of material and lime is obtained, free from all clods or lumps. Materials containing plastic clays or other material which will not readily mix with lime shall be mixed as thoroughly as possible at the time of the lime application, brought to the proper moisture content and left to cure 1 to 4 days as directed by the Engineer. During the curing period the material shall be kept moist as directed by the Engineer.

(b) Final Mixing. After the required curing time, the material shall be uniformly mixed by approved methods. If the soil binder-lime mixture contains clods, they shall be reduced in size by raking, blading, discing, harrowing, scarifying or the use of other approved pulverization methods so that when all nonslaking aggregates retained on the No. 4 sieve are removed, the remainder of the material shall meet the following requirements when tested at the field moisture condition or dry by laboratory sieves:

Minimum Passing	1 3/4" Sieve	100 Percent
Minimum Passing	No. 4 Sieve	60 Percent

Fly ash application is started immediately after the lime modified material has passed the above grading requirement. The time between lime application and fly ash application shall not exceed 4 calendar days. Fly ash shall be applied only to such a limed area that all the operations can be continuous and completed in daylight within 6 hours of such application.

If the material to be stabilized with LFA meets the above gradation in its natural state, the Engineer may elect to apply the fly ash first, followed with the lime application. In any event, it is the intent of this specification to mix and compact the materials within 6 hours after the lime and fly ash have been brought together.

During the interval of time between application and mixing, hydrated lime or fly ash that has been exposed to the open air for a period of 6 hours or more or to excessive loss due to washing or blowing, will not be accepted for payment.

(5) Compaction. Compaction of the mixture shall begin immediately after adding and mixing of the last stabilizing agent and be completed within 6 hours. The material shall be aerated or sprinkled as necessary to provide the optimum moisture. Compaction shall begin at the bottom and shall continue until the entire depth of mixture is uniformly compacted by the method of compaction hereinafter specified as the "Ordinary Compaction" method or the "Density Control" method as indicated on the plans.

When the "Ordinary Compaction" method is indicated on the plans, the following provisions shall apply:

> The material shall be sprinkled and rolled as directed by the Engineer. All irregularities, depressions or weak spots which develop shall be corrected immediately by scarifying the areas affected, adding or removing material as required and reshaping and recompacting by sprinkling and rolling. The surface of the course shall be maintained in a smooth condition, free from undulations and ruts, until other work is placed thereon or the work is accepted.

When the "Density Control" method of compaction is indicated on the plans, the following provisions shall apply:

The course shall be sprinkled as required and compacted to the extent necessary to provide the density specified below as determined by the use of the compaction ratio method:

Description	Density, Percent
For LFA treated subgrade, existing subbase or existing base that will receive subsequent subbase or base courses	Not less than 95 except when otherwise shown on the plans
For LFA treated existing subbase or existing base that will receive surface courses	Not less than 96 except when otherwise shown on the plans

The testing will be as outlined in Test Method Tex-114-E or other approved methods. In addition to the requirements specified for density, the full depth of the material shown on the plans shall be compacted to the extent necessary to remain firm and stable under construction equipment. After each section is completed, tests as necessary will be made by the Engineer. If the material fails to meet the density requirements, the Engineer may require it to be reworked as necessary to meet these requirements or require the Contractor to change his construction methods to obtain required density on the next section.

Throughout this entire operation the shape of the course shall be maintained by blading, and the surface upon completion shall be smooth and in conformity with the typical section shown on the plans and to the established lines and grades. Should the material, due to any reason or cause, lose the required stability, density and finish before the next course is placed or the work is accepted, it shall be reprocessed, recompacted and refinished at the sole expense of the Contractor.

(6) Finishing, Curing and Preparation for Surfacing. After the final layer or course of the LFA treated subgrade, subbase or base has been compacted, it shall be brought to the required lines and grades in accordance with the typical sections.

(a) The resulting base surface shall be thoroughly rolled with pneumatic tire roller and "clipped," "skinned" or "tight bladed" by a power grader to a depth of approximately 1/4 inch, removing all loosened stabilized material from the section. The surface shall then be thoroughly compacted with the pneumatic roller, adding small increments of moisture as needed during rolling. If plus No. 4 aggregate is present in the mixture, one complete coverage of the section with the flat wheel roller shall be made immediately after the "clipping" operation. When directed by the Engineer, surface finishing methods may be varied from this procedure, provided a dense, uniform surface, free of surface compaction planes is produced. The moisture content of the surface material must be maintained at its specified optimum during all finishing operations. Surface compaction and finishing shall proceed in such a manner as to produce, in not more than 2 hours, a smooth, closely knit surface, free of cracks, ridges or loose material conforming to the crown, grade and line shown on the plans.

(b) After the LFA treated course has been finished as specified herein, the surface shall be protected against rapid drying by one of the following curing methods for a period of not less than 3 days or until the surface or subsequent courses are placed:

Maintain in a thorough and continuously moist condition by sprinkling.

Apply a 2-inch layer of earth on the completed course and maintain in a moist condition.

Apply an asphalt membrane to the treated course, immediately after same is completed. The quantity and type of asphalt approved for use by the Engineer shall be sufficient to completely cover and seal the total surface of the base between crown lines and fill all voids. If this method is specified by the Engineer, it shall be the responsibility of the Contractor to protect the asphalt membrane from being picked up by traffic by either sanding or dusting the surface of same. The asphalt membrane may remain in place when the proposed surface or other base courses are placed.

(c) Completed sections of LFA treated material in place may be opened immediately to local traffic and to construction equipment and to all traffic after the curing period, provided the LFA treated course has hardened sufficiently to prevent marring or distorting the surface by equipment or traffic.

5. MEASUREMENT. LFA treatment of the subgrade, existing subbase, and existing base shall be measured by the square yard to neat lines as shown on the typical sections.

When Type A, Hydrated Lime is used, the quantity of lime will be measured by the ton of 2,000 pounds dry weight.

When Type B, Commercial Lime Slurry is used, the quantity of lime shall be calculated from the required minimum percent solids based upon the use of Grade 1, Grade 2, or Grade 3 as follows:

Grade 1: The "Dry Solids Content" shall be at least 31 percent by weight of the slurry and the quantity of lime will be calculated by the ton of 2,000 pounds based on the 31 percent, as delivered on the road.

Grade 2: The "Dry Solids Content" shall be at least 35 percent by weight of the slurry and the quantity of lime will be calculated by the ton of 2,000 pounds based on the 35 percent, as delivered on the road.

Grade 3: The "Dry Solids Content" shall be at least 46 percent by weight of the slurry and the quantity of lime will be calculated by the ton of 2,000 pounds based on the 46 percent, as delivered on the road.

Fly ash will be measured by the ton of 2,000 pounds, dry weight. Fly ash may be applied in dry or in the slurry form. Moisture content in the final mix shall not exceed desired moisture by more than 2 percent unless caused by precipitation.

6. PAYMENT. Work performed and materials furnished as prescribed by this Item and measured as provided under "Measurement" will be paid for as follows:

Lime will be paid for at the unit price bid per ton on 2,000 pounds for "Lime" of the type specified which price shall be full compensation for furnishing all lime.

Fly ash will be paid for at the unit price bid per ton on 2,000 pounds for "Fly Ash" which price shall be full compensation for furnishing all fly ash.

"LFA Treated Subgrade (Ordinary Compaction)," "LFA Treated Existing Subbase (Ordinary Compaction)" and "LFA Treated Existing Base (Ordinary Compaction)" or "LFA Treated Subgrade (Density Control)," "LFA Treated Existing Subbase (Density Control)" and "LFA Treated Existing Base (Density Control)" will be paid for at the unit price bid per square yard. The unit price bid shall be full compensation for all correction of secondary subgrade, for loosening, mixing, pulverizing, spreading, drying, application of lime, application of fly ash, water content of slurry, shaping and maintaining, for all manipulations required, for all hauling and freight involved, for all tools, equipment, labor, and for all incidentals necessary to complete the work except as specified below:

When "Ordinary Compaction" is indicated on the plans, all sprinkling and rolling performed as required will be measured and paid for in accordance with the provisions governing the Items of "Sprinkling" and "Rolling" respectively.

When "Density Control" is indicated on the plans, sprinkling and rolling will not be paid for directly, but the cost of all sprinkling and rolling will be subsidiary to other bid Items.