0822

U.S. Department of Transportation

Federal Highway Administration

Demonstration Projects Program

Demonstration Project No. 59

The Use of Fly Ash in Highway Construction

Lowndes County, Alabama

FHWA-DP-59-3

Initial Report

June 1984

ALABAMA HIGHWAY DEPARTMENT

EVALUATION OF A LIME-FLY ASH-

CEMENT SLURRY PRESSURE INJECTION

OF A ROADWAY EMBANKMENT

PREPARED BY: LARRY LOCKETT
ALABAMA HIGHWAY DEPARTMENT
BUREAU OF MATERIALS AND TESTS
1409 COLISEUM BOULEVARD
MONTGOMERY, ALABAMA 36130

BUREAU OF MATERIALS AND TESTS

EXECUTIVE SUMMARY

The use of lime and lime-fly ash mixtures to increase the shear strength and to decrease the plasticity of clay soils is widely accepted. However, the difficulties involved with treating large quantities of in-situ soils or embankment soils in the traditional manner are also recognized. A relatively new technique for treating troublesome clays in place is through the pressure-injection of a lime-fly ash slurry into the ground.

A slurry of lime, fly-ash, cement and water was pressure injected into an interstate embankment that was experiencing stability problems. The Woodbine Corporation of Fort Worth, Texas was contracted to perform the slurry injection. Hollow steel probes were pushed into the ground by mechanical equipment to a depth of about 10 feet. The slurry was pumped into the ground at intervals of 12 to 18 inches. This process was carried out on a grid with five foot spacings. Then the entire operation was repeated on a similar grid offset halfway between the holes of the first injection.

Since in classical soil mechanics theory it is believed that the shear strength of an unstable soil mass must be increased (or driving forces reduced) to increase the mass's stability, relatively undisturbed samples were removed from the embankment to determine the soil's shear strength before and after treatment of the embankment. The "after" samples were removed following an approximate 30 day in-situ curing period. Laboratory strength tests indicate that the shear strength of the embankment decreased rather than increased. In fact, additional movement of the embankment was initiated during the treatment or injection phase of the project. However, laboratory tests performed prior to treatment indicated that the soils were, by definition, lime-reactive (q_u >50psi) with the addition of 6% lime. Additional tests indicated that the addition of 1½% lime (the maximum amount that can be injected with the system) did not increase the unconfined compressive strength of laboratory specimen, but did alter the Atterberg limits of the soil.

It is hypothesized that subsurface curing at a somewhat suppressed temperature (65°F) for 30 days is not sufficient to allow the necessary pozzolanic compounds to form. It is recommended that future research be instituted that would allow longer term (perhaps several years) monitoring of strength gains due to this potentially slow curing process.

TABLE OF CONTENTS

HEADING	PAGE No.
Executive Summary	1
Table of Contents	2
List of Figures	3
Metric Conversion Table	4
Introduction	5
Preliminary Investigation	5
Design Criteria/Procedure	11
Statistical Considerations	13
Construction Criteria/Procedure	20
Costs of Alternative Materials and Energy Consumption	23
Post Construction Performance	23
Evaluation Procedure	23
Conclusions and Recommendations	23
Appendices	26

Appendix A - Time/Temperature Effects on Unconfined Compressive Strength

Appendix B - Unconfined Compressive Strengths of Shelby Tube Samples

Appendix C - Specifications

Appendix D - Construction Photographs

List of Figures

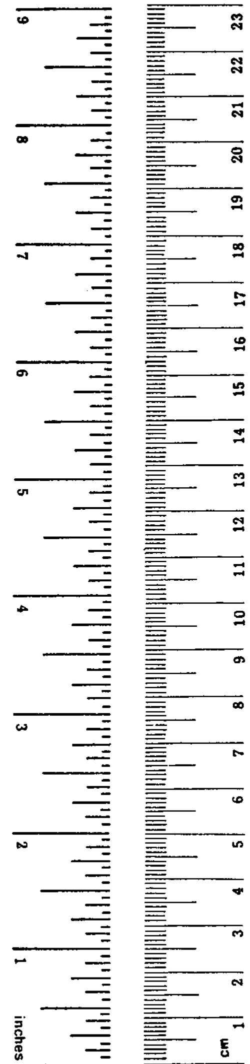
Figure No.	Description	Page No.
1	State Map Showing Black Belt District	6
2	Lowndes County	7
3	Portion of Quadrangle Sheet	8
4	Plan Sheet	9
5	Cross-Sections	10
6	Determination of Lime Reactivity	14
7	Additive Effects on Atterberg Limits	15
8	Log-of-Boring	16
9	Log-of-Boring	17
10	Log-of-Boring	18
11	Log-of-Boring	19
12	Statistical Summary	21
13	Comparison of "Before" & "After" Cases	24

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

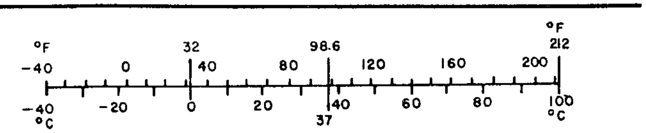
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EVALUATION OF A LIME-FLY ASH-CEMENT SLURRY PRESSURE INJECTION OF A ROADWAY EMBANKMENT

INTRODUCTION

Lime slurry pressure injection has been used extensively by the railroad industry to stabilize heavy clay embankments and/or natural ground subgrades of expansive clay experiencing a phenomenon known in the railway industry as squeeze. Squeeze has been defined as a relatively slow creep-type failure which manifests by extruding failed material upward between the crossties or to the sides of the track. Roadway embankments in the same areas experience similar instabilities, i.e. shallow surface slides due to a time-dependent decrease in shear strength with increasing water content in the clays.

The mechanism by which this lime slurry injection improves the stability of an embankment is not well understood; however, several possible mechanisms have been hypothesized. Formation of sheetlike seams of lime within the subsurface which act as moisture barriers, as well as the more classical modification mechanism (cation exchange and flocculation/agglomeration) and stabilization mechanism (soil-lime pozzolanic reaction) have been suggested in literature involving lime slurry pressure injection. However, in the case of the classical mechanisms no explanation is given concerning how the calcium cations reach the negatively charged clay platelets or how the alumina and silica pozzolans are formed, since no mixing of the soil and lime occur. Introduction of fly ash to the slurry should provide sufficient quantities of alumina and silica to allow the reaction to occur.

A laboratory testing/evaluation plan was performed to gather additional data concerning the lime-fly ash slurry pressure injection technique to improve the stability of a roadway embankment. The site was selected by Mr. W. F. McCullough, Assistant Materials & Tests Engineer & Mr. J. T. McKennon of the Woodbine Corporation, which has extensive experience with this technique.

This research or demonstration project was a joint effort of the Alabama Highway Department, the Federal Highway Administration, Monier Resources, Inc., who supplied the fly-ash, Dravo Natural Resources, who supplied the lime, Martin-Marietta, who supplied the Type I cement, and the Woodbine Corporation, who supplied the labor and equipment at a reduced rate.

PRELIMINARY INVESTIGATION

The site is located in Lowndes County along I-65 about 30 miles south of Montgomery at Milepost 143.6. The area is located at the approximate contact of the Ripley Formation and the Prairie Bluff Chalk of Cretaceous age. Both of these formations are in the Black-Belt or Black Prairie physiographic district and contain a large amount of calcium carbonate and a high percentage of smectite in the clay fraction. See Figures No. 1, 2, & 3. This stretch of interstate is a bifurcated 4-lane with an average daily traffic of 10,920 with 22% truck traffic. The slide is located in a side-hill fill section and is approximately 350 feet long as measured along the toe of the slope. See Figures No. 4 & 5. The distressed embankment section traverses the outlet end of a 5' x 6' roadway culvert. Once the stream discharges from the culvert the water runs parallel to the toe of the slope for approximately 300 feet; however, the

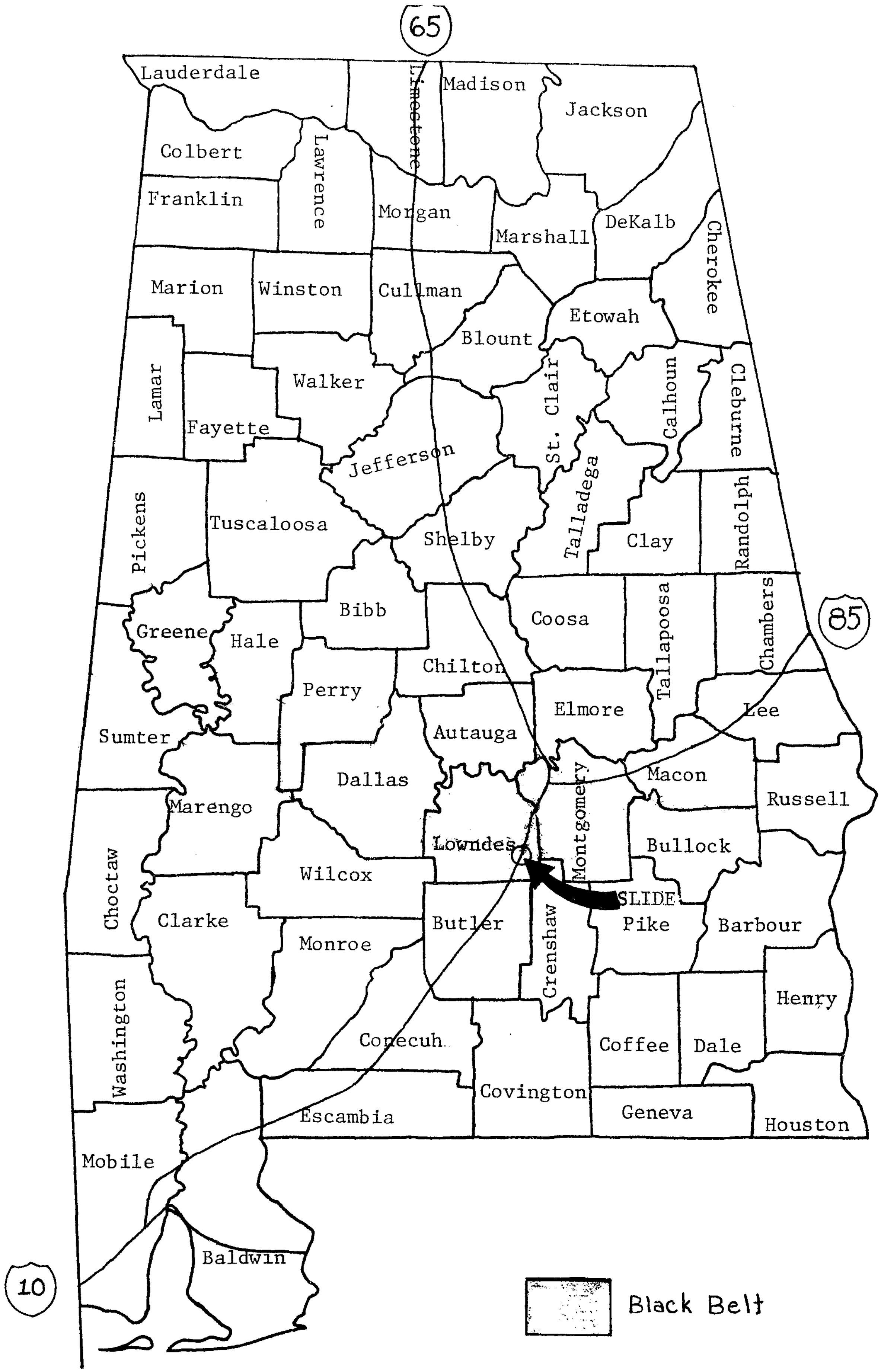

65
Lauderdale
Limestone
Madison
Jackson
Colbert
Lawrence
Franklin
Morgan
Marshall
DeKalb
Cherokee
Marion
Winston
Cullman
Etowah
Blount
Lamar
Walker
St. Clair
Calhoun
Cleburne
Fayette
Jefferson
Talladega
Pickens
Tuscaloosa
Shelby
Clay
Randolph
Bibb
Coosa
Tallapoosa
Chambers
85
Greene
Hale
Chilton
Perry
Elmore
Lee
Sumter
Autauga
Dallas
Macon
Russell
Marengo
Montgomery
Lowndes
Bullock
Choctaw
Wilcox
SLIDE
Clarke
Butler
Pike
Barbour
Monroe
Crenshaw
Washington
Henry
Conecuh
Coffee
Dale
Covington
Escambia
Geneva
Houston
Mobile
Baldwin
10
Black Belt

Figure No. 1

Figure 2

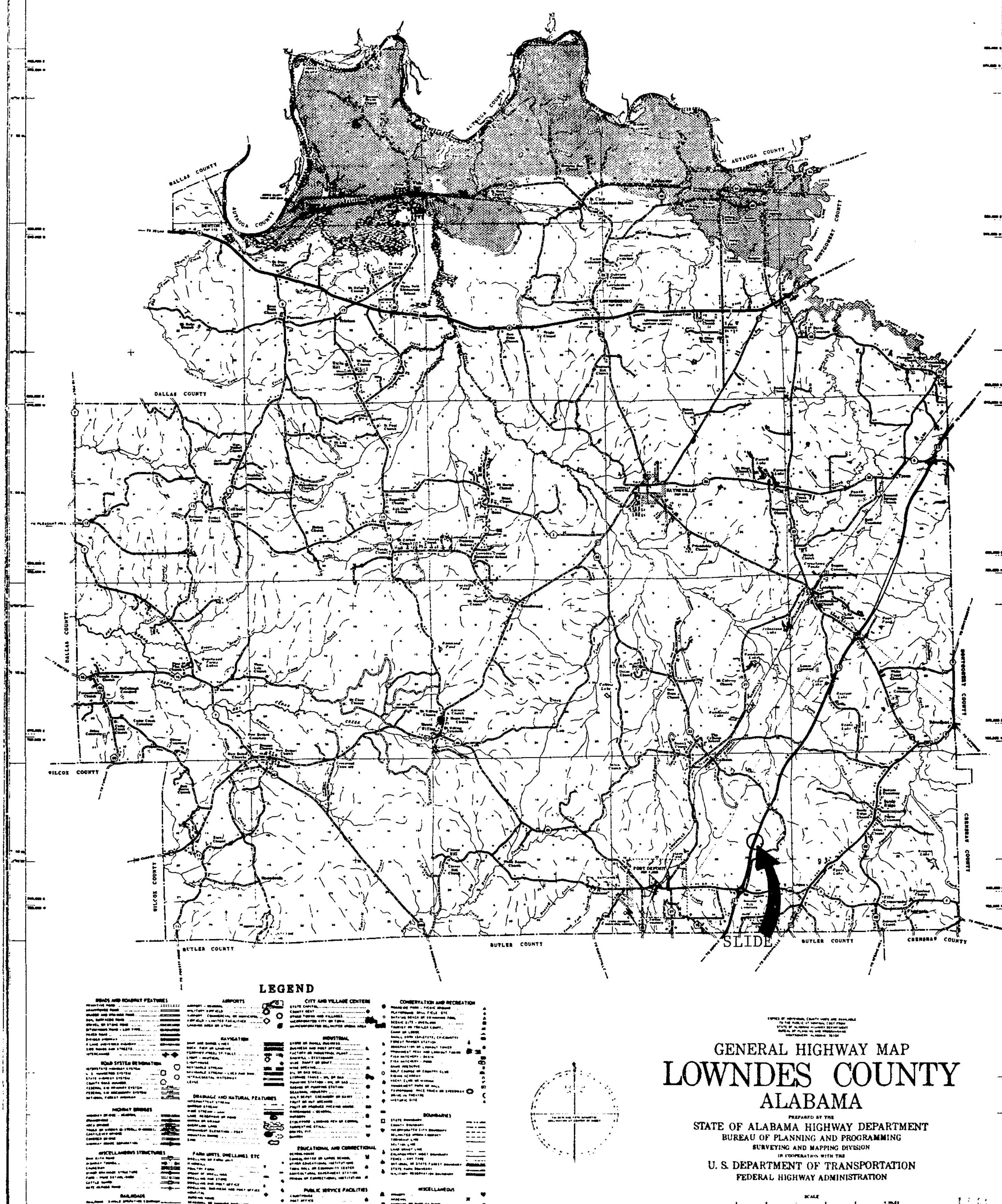

AUTAUGA COUNTY
DALLAS COUNTY
MONTGOMERY COUNTY
WILCOX COUNTY
BUTLER COUNTY
CRENSHAW COUNTY
HAYNEVILLE
FORT DEPOSIT
SLIDE
LEGEND
GENERAL HIGHWAY MAP
LOWNDES COUNTY
ALABAMA
PREPARED BY THE
STATE OF ALABAMA HIGHWAY DEPARTMENT
BUREAU OF PLANNING AND PROGRAMMING
SURVEYING AND MAPPING DIVISION
IN COOPERATION WITH THE
U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

Figure 3

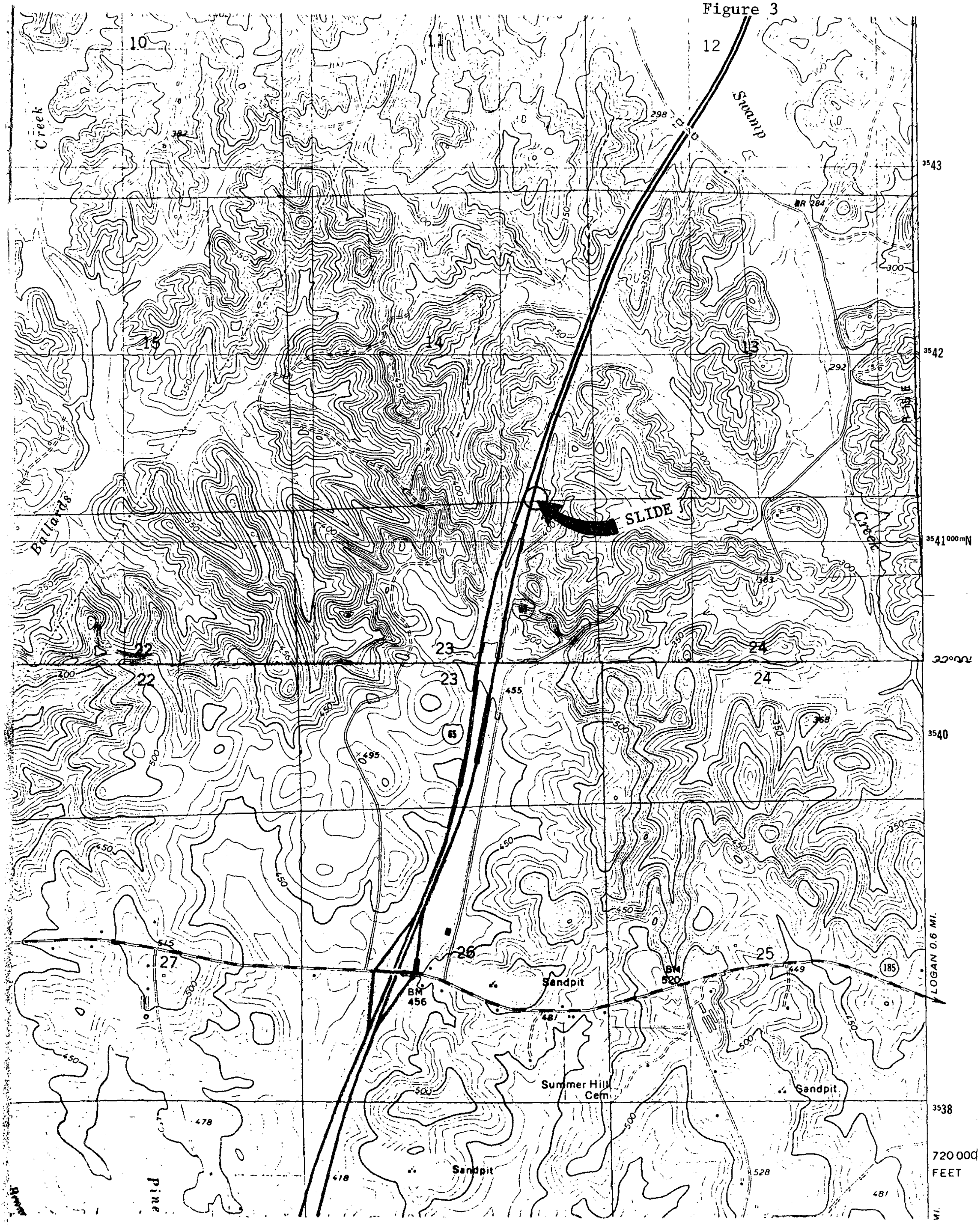

SLIDE
Swamp
Creek
Ballards
Creek
Pine
Sandpit
Sandpit
Sandpit
Summer Hill Cem
BM 456
BM 520
LOGAN 0.6 MI.
3541000mN
720 000
FEET
10
11
12
13
14
15
22
23
24
25
26
27

Figure 4.

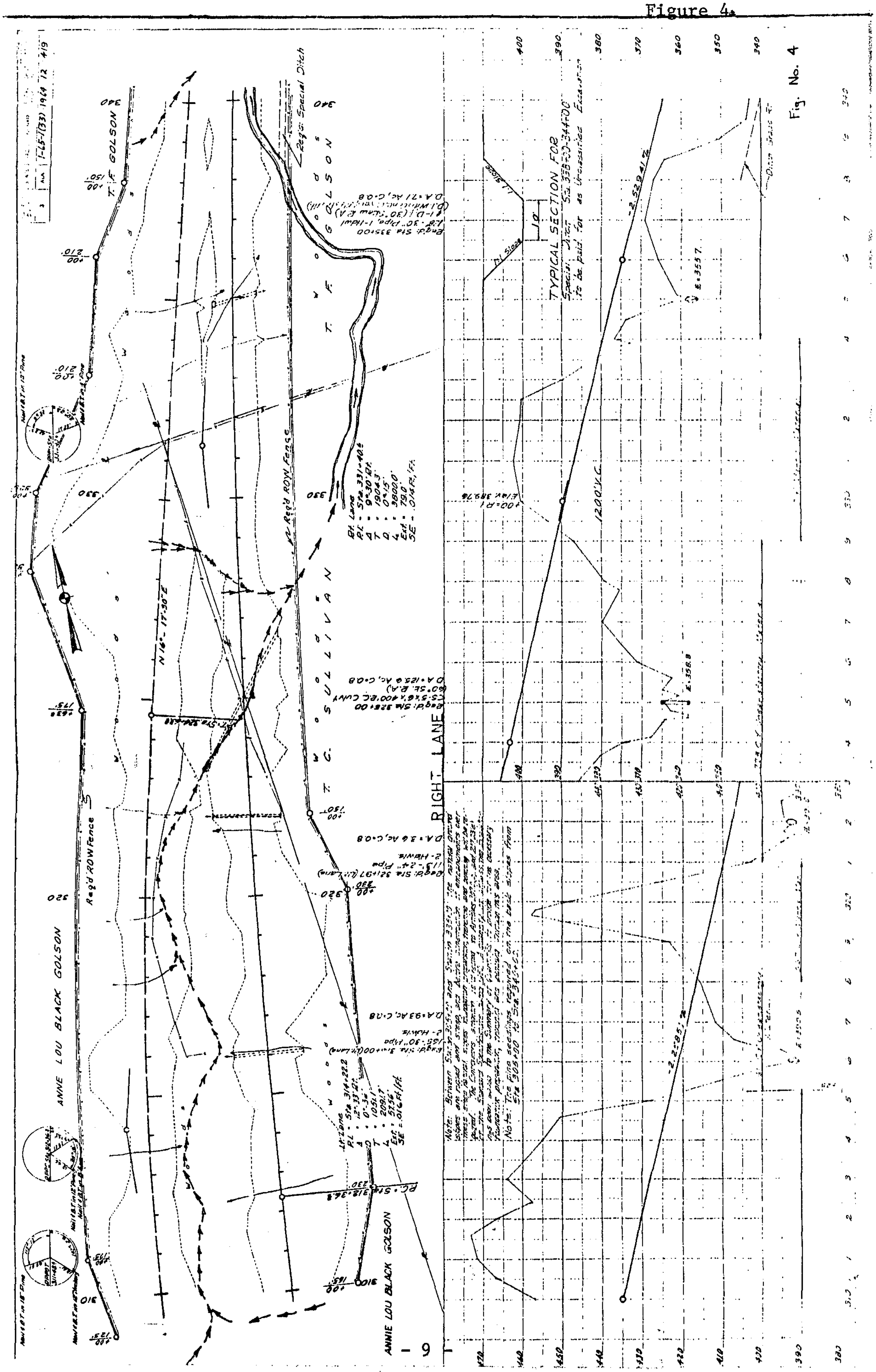


Fig. No. 4
TYPICAL SECTION FOR
RIGHT LANE
ANNIE LOU BLACK GOLSON
T. F. GOLSON
T. G. SULLIVAN
Req'd ROW Fence
1200' V.C.

Figure 5

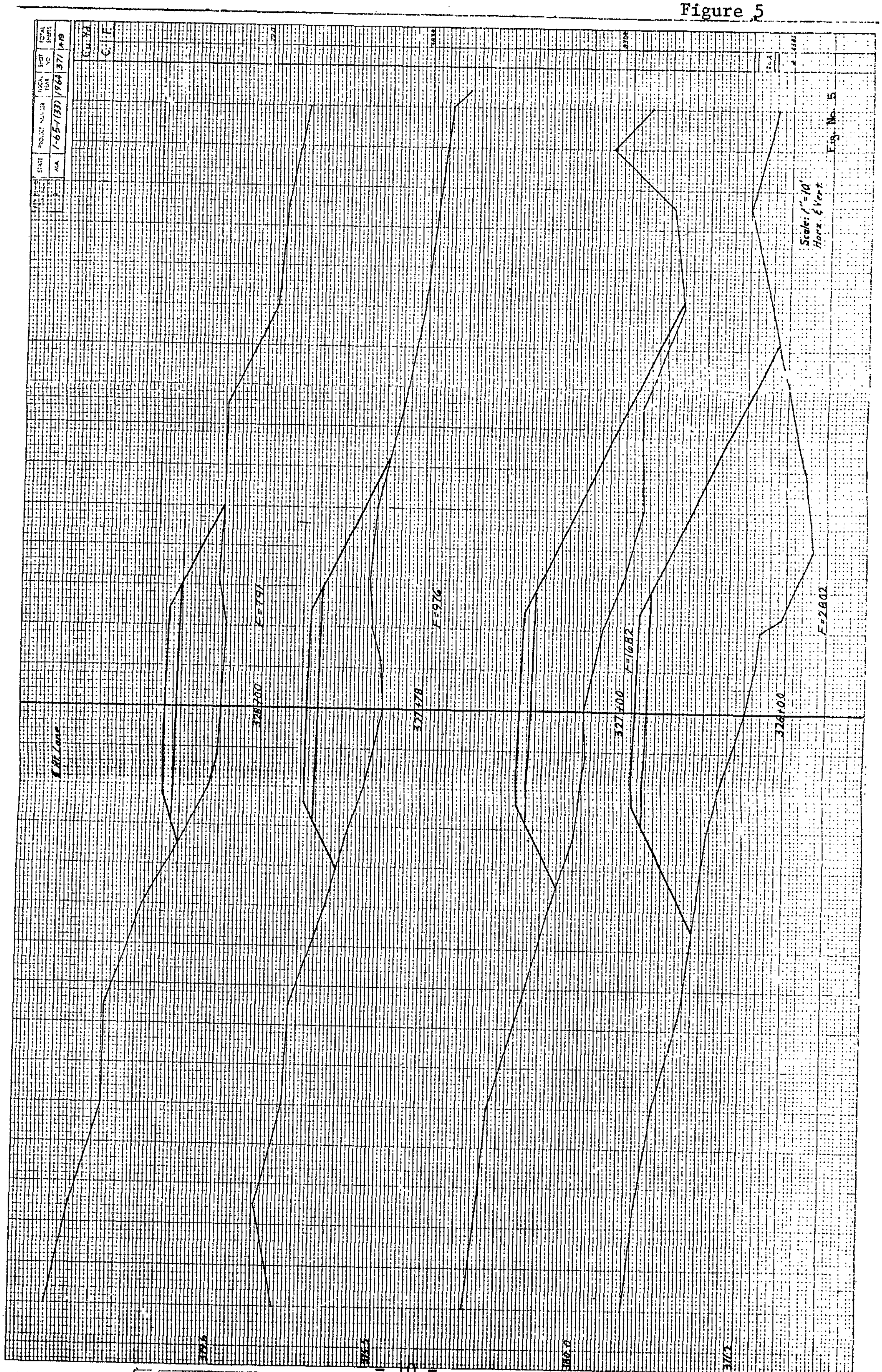


Fig. No. 5
Scale: 1"=10'
Horz. & Vert.
F=791
F=976
F=1682
F=2802
328+00
327+78
327+00
326+00
℄ Rt Lane

significance of this orientation was not recognized until the construction phase and the area cleared of undergrowth. This section of Alabama experiences approximately 50 inches of rainfall per year; therefore, the toe of the slope is usually wet.

It is believed that in order to improve the stability of an embankment, either the shear strength of the materials within or below the embankment must be increased, or the seepage forces acting on the embankment must be decreased. Laboratory evaluation of relatively undisturbed Shelby tube soil samples tested in unconfined compression from this embankment experiencing instability problems both prior to and after the lime-fly ash injection should provide insight concerning the shear strength of the embankment materials and the mechanism that produces any apparent increase in stability. Also, since not all clays are lime reactive, background data concerning the lime reactivity of the soil should be gathered. The design of the laboratory evaluation is as follows:

1. Determine laboratory strength increase (lime-reactivity) of material within the embankment using statistical analyses.

2. Determine laboratory strength increase (lime-fly ash reactivity) of material within the embankment using statistical analyses.

3. Determine unconfined compressive strength of relatively undisturbed Shelby samples obtained from the embankment prior to and after injection.

4. Use statistical analyses to determine, at some level of confidence, if an appreciable strength gain has occurred after injection.

Design Criteria/Procedure

Initially the Woodbine Corporation proposed to use a Class C Fly-Ash produced in Texas for the project. However, it was pointed out to Woodbine that the transportation costs associated with importing fly-ash from Texas would negate any economic effects of this type treatment. Therefore, Woodbine decided to use locally produced fly-ash but to add 1% Type I Portland cement to exhance any strength gain.

The lime used in this project was Longview Airfloated High Calcium Lime, $Ca(OH)_2$, processed such that 86 percent is finer than a number 325 sieve (0.045mm). This lime, compliments of the Longview Lime Products Division of the Dravo Natural Resources Company, was derived from the Newalla Limestone (almost pure calcium carbonate) near Saginaw, Alabama. The chemical analysis of the lime is presented below:

CONSTITUENT*	% By Weight
Calcium Hydroxide, $Ca(OH)_2$	94.2
Silica, SiO_2	1.0
Magnesium Oxide, MgO	2.4
Calcium Carbonate, $CaCO_3$	1.0
Free Water, H_2O	0.5
Aluminum & Ferric Oxide, Al_2O_3 Fe_2O_3	0.7
Potassium Oxide, K_2O	0.1
Sodium Oxide, Na_2O	0.1
	100.0

*As determined by Longview Lime Products Division of Dravo Natural Resources Company.

The fly ash used in this project was produced at the Alabama Power Company's E. C. Gaston Steam Generating Plant at Wilsonville, Alabama. The Wilsonville fly ash is a Class F fly ash processed such that 85-90% passes the number 325 sieve and with a percent loss on ignition of 4-5%. The fly ash was compliments of Monier Resources, Inc. The chemical analysis of the lime is presented below:

CONSTITUENT*	% By Weight
Silica, SiO_2	43.56
Alumina, Al_2O_3	32.55
Magnesia, MgO	1.42
Sulphur Trioxide, SO_3	.71
Available Sodium Oxide, Na_2O	.03
Available Potassium Oxide, K_2O	.13
Alkali, Calculated as Sodium Oxide, Na_2O	.12
Ferric Oxide, Fe_2O_3	11.30
Moisture Content, H_2O	.03

*As determined by the Alabama Highway Department (5-31-83)

The 1st task undertaken was to determine the properties of the soil to be treated and how it would react when mixed with lime, and lime-fly ash and cement. Figure No. 6 indicates the procedure followed: i.e., 5 unconfined compression samples of the remolded raw soil, the lime-soil mixture, and the lime-fly-ash-cement-soil mixture were prepared and cured at an elevated temperature (49°C) for 48 hours to allow the specimens to cure at an accelerated rate.

Figure No. 7 indicates the effect of the lime, or lime-fly ash-cement additive on the Atterberg limits of the soil. During the later stages of the project, Mr. Mac McKennon of Woodbine indicated that approximately 1½% solids is the maximum that they can inject into the soil. Therefore, additional tests were run with 1½% lime - Figure No. 7 also indicates that 1½% lime is sufficient to improve or modify the soil and reduce the plasticity.

Also, prior to treatment, numerous undisturbed Shelby samples were taken in the upper scarp area. See Figures No. 8 & 9 for the logs-of-borings. These samples were stored until additional samples were taken after the area was treated (Figures No. 10 & 11) and then all samples were tested in unconfined compression. However, it is noteworthy that these strengths are not indicative of an embankment in distress.

The laboratory testing was divided into several phases. The first phase was designed to determine the soil's lime-reactivity as defined by Thompson, i.e. if the change in the unconfined compressive strengths of the raw soil and the lime-treated soil after a curing period of 48 hours at 120°F is greater than or equal to 50psi, the soil is termed lime reactive. This first phase was also designed to reflect the effects of the lime on the plasticity of the soil. This first phase was composed of five unconfined compressive strength samples with lime and five samples without lime for each layer of material within the embankment. Atterberg limit determinations were made on each treated and untreated batch of material. See Figure No. 7. Based on visual observation (color, consistency, etc.), there appeared to be 4 distinct layers; 3-4 feet, 4-10 feet, 10-19 feet, and 19-28 feet. These materials were removed from the embankment by auger borings. See Figures No. 8 & 9. The individual strength samples were prepared in a Harvard miniature mold at the optimum moisture contents and unit weights as determined by Proctor density tests on the raw soil and on the lime treated soil. Appendix A lists the results of this unconfined compression testing.

Statistical Considerations - In order to minimize random testing variations associated with repetitive strength testing of identical lime-soil specimens, a sample population composed of five lime-treated and five untreated (control) specimens was planned for each soil series. This information will allow adequate statistical significance tests to be conducted, i.e., to determine if the means of the treated and untreated strength data sets are significantly different by more than 50psi with some level of confidence. Since the variances ($S_1 2$ and $S_2 2$) of the lime-treated and untreated specimens strength population are unknown, the modified "t"-test of hypothesis, which does not assume homogeneous population variances, is used.

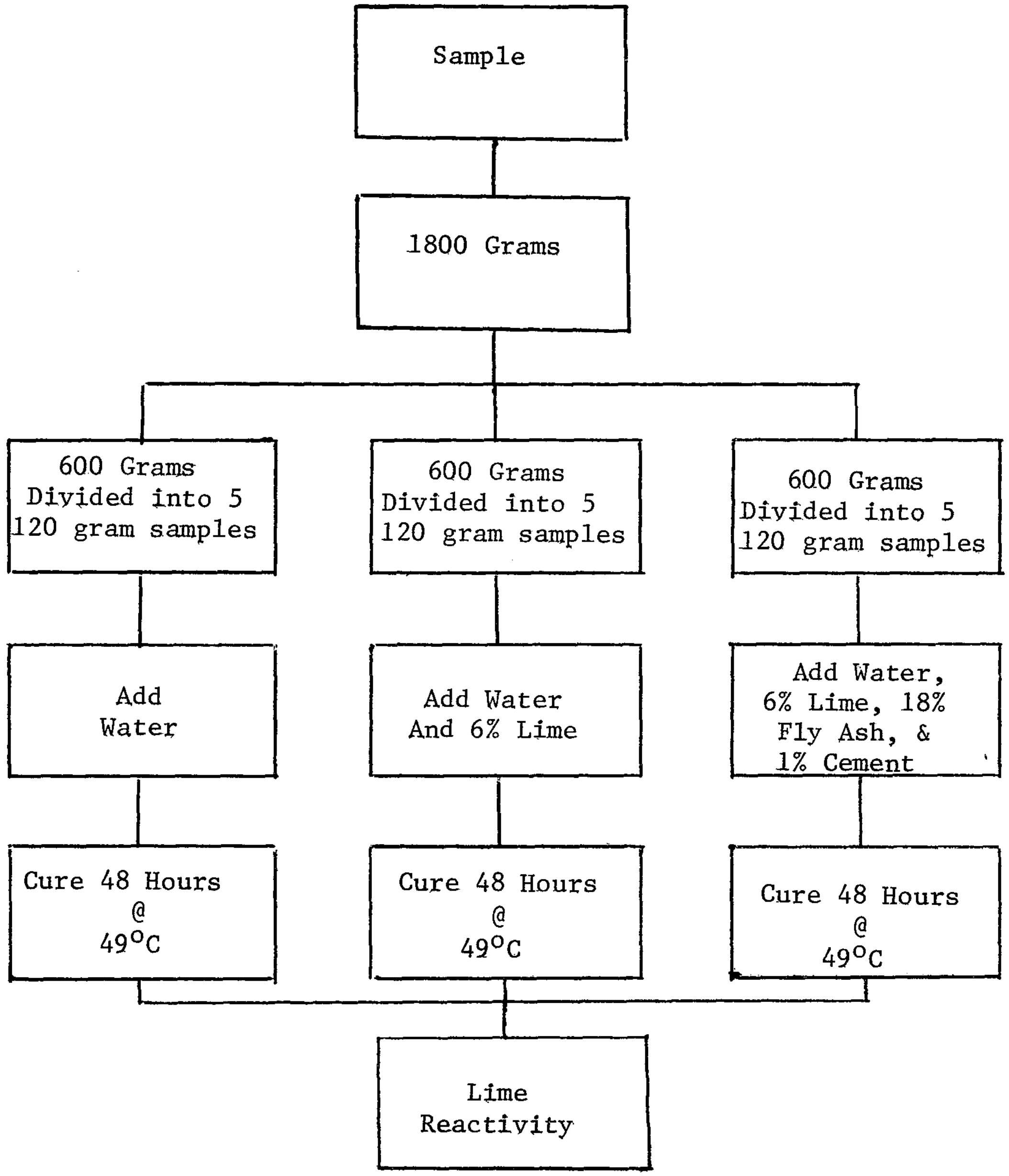

Sample
1800 Grams
600 Grams Divided into 5 120 gram samples
600 Grams Divided into 5 120 gram samples
600 Grams Divided into 5 120 gram samples
Add Water
Add Water And 6% Lime
Add Water, 6% Lime, 18% Fly Ash, & 1% Cement
Cure 48 Hours @ 49°C
Cure 48 Hours @ 49°C
Cure 48 Hours @ 49°C
Lime Reactivity

Figure 6

ADDITIVE EFFECTS ON ATTERBERG LIMITS

DEPTH	Untreated L.L.	Untreated P.L.	Untreated P.I.	Treated (6% Lime) L.L.	Treated (6% Lime) P.L.	Treated (6% Lime) P.I.	P.I. Change w/6% Lime	6% Lime 18% Fly Ash 1% Cement L.L.	6% Lime 18% Fly Ash 1% Cement P.L.	6% Lime 18% Fly Ash 1% Cement P.I.	P.I. Change w/6% Lime 18% Fly Ash 1% Cement
3.0'-4.0'	49.0	28.0	21.0	46.0	42.0	4.0	17.0	42.0	39.0	3.0	1.0
4.0'-10.0'	46.0	30.0	16.0	47.0	45.0	2.0	14.0	N.P.	N.P.	N.P.	-
10.0'-19.0'	48.0	26.0	22.0	44.0	39.0	5.0	17.0	40.0	35.0	5.0	0
19.0'-28.0'	48.0	24.0	24.0	44.0	39.0	5.0	19.0	42.0	35.0	7.0	-2

DEPTH	Treated (1½% Lime) L.L.	Treated (1½% Lime) P.L.	Treated (1½% Lime) P.I.	P.I. Change w/1½% Lime
4.0' - 10.0'	44	43	1	15
10.0'- 19.0'	46	38	8	16

Figure No. 7

BMT 123
Rev. 1-1-76

STATE OF ALABAMA HIGHWAY DEPARTMENT
BUREAU OF MATERIALS AND TESTS
GEOTECHNICAL SECTION
TEST BORING RECORD

LOCATION: MP 143.62 NBL I-65

ELEV. DEPTH: 0.0, 0.5, 1.0, 9.0, 10.0, 15.0, 17.0, 18.0, 19.0, 21.0, 22.0, 24.0, 25.0, 27.0, 30.0

DESCRIPTION	N	CR	S	REMARKS
Asphalt				
Medium moist red & tan clayey sand			☒	1-A Figure No. 8
Medium moist brown & gray silty sandy clay			☒	1-B
			☒	1-C
Medium damp brown & gray silty clay			☒	1-D
Medium moist gray silty clay w/a few marine shells			☒	1-E
Medium moist gray & tan silty sandy clay			☒	1-F
Medium moist brown & gray sandy clay				
Medium moist gray & tan silty clay			☒	1-G
Medium moist gray & tan sandy clay			☒	1-H
Medium moist gray & tan silty clay				
Medium moist gray clay w/a few small shells			☒	1-I
			☒	1-J
Medium moist brown & gray silty clay				
Stiff moist gray & tan silty sandy clay				
Very stiff moist gray & tan sandy clay w/silt				

Boring No. 1 approximately 25' south of slide mass center and at east edge of paved shoulder.

No water table

N — IS PENETRATION IN BLOWS PER FOOT (ASTM D-1586)

CR — IS % CORE RECOVERY, NX OR AX DESIGNATES BIT SIZE (ASTM D-2113)

S — SYMBOLS DESCRIBED BELOW:

N	CR	S	
5			
18	70 NX	☒	UNDISTURBED SAMPLE (ASTM D-1587)
	100		WATER TABLE, TIME OF BORING
23	AX		WATER TABLE, 24 HOUR READING
		◀	LOSS OF DRILLING FLUID

PROJECT Fort Deposit Slide

DIVISION 6

COUNTY Lowndes

DATE DRILLED 1/5/82

BORING-XXXXX NO. 1

Scale: 1"=10'

BMT 123
Rev. 1-1-76

STATE OF ALABAMA HIGHWAY DEPARTMENT
BUREAU OF MATERIALS AND TESTS
GEOTECHNICAL SECTION
TEST BORING RECORD

LOCATION: MP 143.62 NBL I-65

ELEV.	DEPTH	DESCRIPTION	N	CR	S	REMARKS
	0.0					
	0.5	Asphalt			2-A	Figure No. 9
	1.0	Medium damp red very sandy clay				
	2.0	Medium damp brown clayey sand				
	4.0	Medium moist brown & gray silty sandy clay				
	7.0	Medium moist gray very silty sandy clay			2-B	
	11.0	Medium damp brown & gray silty clay			2-C	
	15.0	Medium moist brown, tan & gray sandy clay			2-D	
	16.0	Medium moist tan & gray sandy clay w/silt	20.5 18			
	20.0	Stiff moist brown & gray clay				
		Very stiff moist brown, tan & gray clay w/some sand & silt	23.5 17		2-E	
	25.0	Stiff moist gray & tan clay w/ some silt				
	26.0	Very stiff moist gray & tan sandy clay	29.5 25			
	28.0	Very stiff moist gray & tan silty clay				
	29.5					

Boring #2 approximately 25' north of the slide mass center and at the east edge of the paved shoulder

N — IS PENETRATION IN BLOWS PER FOOT (ASTM D-1586)

CR — IS % CORE RECOVERY, NX OR AX DESIGNATES BIT SIZE (ASTM D-2113)

S — SYMBOLS DESCRIBED BELOW:

5
18 70 NX
100
23 AX

UNDISTURBED SAMPLE (ASTM D-1587)

WATER TABLE, TIME OF BORING

WATER TABLE, 24 HOUR READING

LOSS OF DRILLING FLUID

PROJECT Fort Deposit Slide

DIVISION 6

COUNTY Lowndes

DATE DRILLED 1/5/82

BORING-~~BENT~~ NO. 2

Scale: 1" = 10'

SMT 123
Rev. 1-1-76

STATE OF ALABAMA HIGHWAY DEPARTMENT
BUREAU OF MATERIALS AND TESTS
GEOTECHNICAL SECTION
TEST BORING RECORD

LOCATION: MP 143.62 NBL I-65

ELEV.	DEPTH	DESCRIPTION		N	CR	S	REMARKS
	0.0	Hard dry red sandy clay w/gravel					Figure No. 10
	2.0	Stiff moist brown, red, & gray silty clay w/some sand	3.5	14			1-C
			7.5	12			1-F
	9.0	Very stiff moist brown & gray silty clay	12.5	16			1-I
	13.5	Stiff moist gray & brown silty clay	17.5	8			1-L
	18.5	Stiff moist brown & gray silty clay w/some sand	22.5	14			1-O
	23.5	Very stiff moist brown & gray silty clay	27.5	23			1-R
	26.0	Very stiff dry gray silty sandy clay					
	28.5	Very stiff moist gray silty sandy clay	32.5	31			
	31.5	Hard moist gray silty sandy clay					
	33.5						

REMARKS:

Boring No. 1 approximately 25' south of slide mass center and at east edge of paved shoulder.

No Water Table

N — IS PENETRATION IN BLOWS PER FOOT (ASTM D-1586)

CR — IS % CORE RECOVERY, NX OR AX DESIGNATES BIT SIZE (ASTM D-2113)

S — SYMBOLS DESCRIBED BELOW:

5			
18	70 NX		UNDISTURBED SAMPLE (ASTM D-1587)
	100		WATER TABLE, TIME OF BORING
23	AX		WATER TABLE, 24 HOUR READING
			LOSS OF DRILLING FLUID

PROJECT Fort Deposit Slide

DIVISION 6

COUNTY Lowndes

DATE DRILLED 8/25/83

BORING- NO. 1

Scale: 1" = 10'

BMT 123
Rev. 1-1-76

STATE OF ALABAMA HIGHWAY DEPARTMENT
BUREAU OF MATERIALS AND TESTS
GEOTECHNICAL SECTION
TEST BORING RECORD

LOCATION: MP 143.62 NBL I-65

ELEV. DEPTH: 0.0, 1.5, 2.5, 3.5, 4.5, 9.5, 10.5, 12.5, 18.5, 22.0, 23.5, 26.0

DESCRIPTION	N	CR	S	REMARKS
Hard dry brown & red sandy clay w/gravel			☒	2-A Figure No. 11
Stiff moist brown & red silty sandy clay			☒	2-C
Stiff moist brown & gray silty clay w/some sand			☒	2-D
Hard dry gray silty clay			☒	2-F
Stiff moist gray silty clay w/some sand			☒	2-G
Very stiff moist brown & gray silty clay w/some sand			☒	2-H
Very stiff moist brown & gray silty clay			☒	2-J
Very stiff moist gray silty clay w/some sand	26.0	26	☒	2-K
Stiff moist brown & gray silty clay w/some sand			☒	2-M
Very stiff dry brown & gray silty clay w/some sand			☒	2-N
Very stiff moist gray silty clay w/some sand				

REMARKS: Boring #2 approximately 25' north of the slide mass center and at the east edge of the paved shoulder.

No Water Table

N — IS PENETRATION IN BLOWS PER FOOT (ASTM D-1586)

CR — IS % CORE RECOVERY, NX OR AX DESIGNATES BIT SIZE (ASTM D-2113)

S — SYMBOLS DESCRIBED BELOW:

5			
18	70 NX	☒	UNDISTURBED SAMPLE (ASTM D-1587)
	100		WATER TABLE, TIME OF BORING
23	AX		WATER TABLE, 24 HOUR READING
		◀	LOSS OF DRILLING FLUID

PROJECT Fort Deposit Slide

DIVISION 6

COUNTY Lowndes

DATE DRILLED 8/26/83

BORING ~~XEXNT~~ NO. 2

Scale: 1" = 10'

The null and alternate hypotheses are as follows:

H_o: $(\mu 1 - \mu 2) \leq 49.99$ psi (soil is not lime-reactive)

H_a: $(\mu 1 - \mu 2) > 49.99$ psi (soil is lime-reactive)

The test statistic for each soil series is calculated by the formula:

$$t = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{\sqrt{(S_1^2 + S_2^2)/n}}$$

Where n =sample size

$\bar{X}_1$ =mean q_u of lime-treated soil

$\bar{X}_2$ =mean q_u of untreated soil

$\mu_1 - \mu_2$ =desired difference in means (50 psi)

S_1^2 =sample variance in lime-treated soil

S_2^2 =sample variance in untreated soil

After the"t" statistic is calculated, the probability of rejecting a correct hypothesis (Type 1 or alpha error) can be determined by consulting a table presenting the distribution of "t" with (n-1) degrees of freedom instead of (2n-2) to compensate for the effects of possible non-homogeneous variances of the two sample populations. Therefore, the alpha level so determined is the probability of error associated with declaring a soil as lime-reactive based on the data presented (ten unconfined compressive strength tests). See Figure No. 12 for the statistical summary.

Construction Criteria/Procedure

The site was prepared by state forces by removal of vegetation and smoothing of the slope by a small dozier. This included obliterating the slide scarp and backfilling of the small stream course along the toe of the slope. Also, the culvert's headwall and wingwall were removed (one wingwall had previously been removed by the force of the slide) to better accommodate the injection equipment.

After the site was prepared, the contractor hauled an 18,000 gallon mixing tank to the site. Water, purchased from the City of Greenville, was hauled to

STATISTICAL SUMMARY

Soil Depth	Raw Soil Mean qu (psi)	6% Lime Mean qu (psi)	Calculated "t"	Alpha Level	6% Lime 18% Fly Ash, 1% Cement Mean qu (psi)	Calculated "t"	Alpha Level	1½% Lime Mean qu (psi)	Calculated "t"	Alpha Level
3' - 4'	$\bar{x}$=44.58 s= 3.72	$\bar{x}$=437.72 s=183.23	4.19	.02	$\bar{x}$=277.42 s= 10.09	38.02	$\ll$.0005			
4' - 10'	$\bar{x}$=33.88 s= 5.66	$\bar{x}$=279.76 s=205.58	2.13	.05	$\bar{x}$=257.86 s= 10.23	33.28	$\ll$.0005	$\bar{x}$=42.40 s= 8.40	-9.14	1.0
10'-19'	$\bar{x}$=38.56 s= 2.97	$\bar{x}$=378.74 s=178.69	3.63	.01	$\bar{x}$=308.78 s= 31.70	15.47	$\ll$.0005	$\bar{x}$=49.56 s= 5.53	-13.88	1.0
19' - 28'	$\bar{x}$=36.66 s= 4.45	$\bar{x}$=374.38 s= 97.60	6.59	.003	$\bar{x}$=250.56 s= 19.02	18.76	$\ll$.0005			

Figure No. 12

the site and pumped into the tank. Then lime and fly ash were hauled in bulk in the same tanker truck and pneumatically unloaded into the tank - the lime was pumped into the mixing tank first in order to help suspend the heavier fly ash and keep it from falling to the bottom of the tank. The slurry was mixed and agitated with a system of paddles built into the tank. See photographs 1 - 3 in Appendix D. After the slurry was sufficiently mixed, it was pumped to a smaller holding tank mounted on a rig capable of injecting to a depth of 40 feet. The cement was added to the slurry in this holding tank. However, this large rig was simply used as a pumping station for the majority of this project. The slurry was actually injected with a small rubber-tired fork lift modified such that it could inject to a depth of ten feet. Later in the project the contractor substituted a small tracked tractor with much better maneuverability to perform the injection. See photographs No. 4 & 5.

As mentioned previously, an old creek bed paralleled the toe of the slope for some 300 - 350 feet and the area was quite wet. Therefore, the contractor attempted to construct a cut-off wall with the slurry by making the first injection pass along and parallel to the toe of the embankment. Thereafter, injection passes were made perpendicular to centerline. The contractor's 4 man crew performed an initial injection all over the site at 5' on centers to depths outlined below of a 3 to 1 mix of fly ash and hydrated lime, at a specific gravity of approximately 1.26 to 1.27. Due to the nature of the type of fly ash utilized, bagged Type I cement (also some Type III cement was used when the supply of Type I was expended) was added as an accelerator of strength development at the rate of about 1% of the total amount of fly ash and lime used.

The injection pattern on the first injection was 5 feet on centers and 10 feet deep except the row closest to the paved shoulder on top was injected with a rig capable of injecting to 40 feet deep and most of the injections in that row achieved depths of more than 30 feet. See photograph No. 7. The actual injection was performed by inserting the injector tips to the full depth and pumping the slurry to "refusal." This procedure was repeated at 12" - 18" intervals as the injector was withdrawn toward the surface. The injector tips were designed such that the slurry was dispersed in a 360 degree pattern. "Refusal" was defined as that point at which the maximum amount of slurry has been injected into the soil and the slurry begins to run freely at the surface from previous injection holes or from areas where the surface soils have fractured. At times the slurry would erupt from the ground a distance of over 50 feet from the injection point. See photograph No. 6. A total of 121.8 tons of fly ash and 45.4 tons of hydrated lime were initially injected between June 6 and June 14, 1983. However, based on the evaluation of the soils at the site by the contractor and the results of the laboratory tests, the decision was made to use straight hydrated lime for the second injection, which was offset midway between the holes of the first injection pass. The same layout was used on the second injection as for the first, that is, the 40 ft. rig was used on the top row and the 10 ft. equipment was used everywhere else. A total of 75.8 tons of hydrated lime was injected during the second injection pass at an average specific gravity of about 1.15. This work was completed and the contractor's injection equipment was moved away from the site on June 19, 1983.

During the injection operation some movement of the slide occurred as evidenced by the reappearance of the upper scarp. See photographs No. 9 & 10. However, this movement was toward the end of two days of rain, and it is unknown if the movement was due to rainfall or to the injection process itself, i.e. possibly the addition of water or the addition of the ball bearing-like fly ash in the slurry.

In any case the Department's engineers felt it prudent to add a rock buttress at the toe of the slope along the stream course to prevent additional movement. After the buttress was constructed, the embankment slope was benched in order to rebuild the slope. During this benching operation, the presence of the finger like sheets of slurry was evident in the face of the benches - these sheets were also evident in the extruded Shelby samples. See photograph No. 8.

The slope was then restored to a uniform 3:1 slope (approximately) and seeded with a winter grass. See photographs No. 11 & 12. This work was completed on October 3, 1983.

Costs of Alternative Materials and Energy Consumption

These two sections are not applicable to this particular project since there was no true alternative to utilizing fly ash. The Fly ash was added to the slurry in an effort to be assured that sufficient amounts of the silica (SiO_2) and alumina (Al_2O_3) pozzolans were present in the soil to enable the formation of the cementing agents which increase the shear strength of the soil. It has been previously determined or postulated that the addition of fly ash to silts and some of the Black Belt soils that were not shown to be lime reactive (i.e. exhibits a shear strength gain in excess of 50psi with the addition of $6^{\pm}\%$ lime) would exhibit an increase in strength due to the added silicas and aluminas.

Post Construction Performance & Evaluation Procedure

The construction was completed on the Demonstration Project #59 using a Lime-Fly Ash mixture to stabilize a landslide on I-65 at milepost 143.6 right of north-bound lane. The method used to treat the slide was pressure injection. Construction and preliminary investigation have been completed and submitted.

For five years following completion of construction, December 1983, the project will be inspected on an annual basis and reported through the continuing HPR Research Project 930-085, "Evaluation of Experimental Features on Construction Project." Future evaluations will be visual. Signs of failure will be noted and reported. The first signs of failure will be tension cracks or other slope distress.

Conclusions & Recommendations

As shown in Figure No. 13, which makes a comparison of the unconfined compressive strengths of the "Before" and "After" cases, it is noteworthy that the strengths actually decreased rather than increased. Appendix B lists the unconfined compressive strengths for all the Shelby tube samples. However, observations of the Shelby tube samples once extruded revealed the presence of the finger like sheets of slurry throughout the treated area. After a curing period of approximately 30 days, the injected material was still in a plastic state. Therefore, a series of man-made failure surfaces were introduced into the unconfined compression samples.

"BEFORE"	"AFTER"
Boring 1	Boring 1
$\bar{x}$=4265 PSF	$\bar{x}$=2702 PSF
s=1467 PSF	s=1201 PSF
Boring 2	Boring 2
$\bar{x}$=5446 PSF	$\bar{x}$=3080 PSF
s=4277 PSF	s=1352 PSF

Figure No. 13

In conclusion, it is apparent that 30 days of subsurface curing is not comparative to the accelerated curing program used in the laboratory. The temperature of the subsurface soils should approximate that of Central Alabama's mean annual air temperature (65°F). Therefore, there is a significant difference in the number of degree-days between this project and Alabama's previous experience with near surface curing of roadway materials. This difference in curing environments may account for the difference in strengths and/or maturity. Maturity has been defined as the product of curing temperature and its duration.

It is recommended that future research of this type consider selecting a site that is entirely embankment with no complicating drainage structures in the immediate area. It is also suggested that the duration of the research be of a sufficient period that would allow the monitoring and measurement of any soil strength gain over a period of several years due to the potential for the slow curing process as outlined above.

APPENDICES

Appendix A - Time/Temperature Effects on Unconfined Compressive Strength

Appendix B - Unconfined Compressive Strengths of Shelby Tube Samples

Appendix C - Specifications

Appendix D - Construction Photographs

APPENDIX A

TIME/TEMPERATURE CURING EFFECTS ON UNCONFINED COMPRESSIVE STRENGTH

Cured at 49°C (120°F) for 48 Hours Without Lime

Soil Depth	Unconfined Compressive Strength (psi)	Moisture Content (%)	Specimen Weight (Before) Curing (grams or pcf)	UNCT
3' - 4'	42.3	18.5	116.5	116.0
	48.2	19.6	123.2	122.2
	43.7	18.7	118.6	117.7
	40.1	19.3	119.7	119.1
	48.6	18.6	120.0	119.4
	$\bar{x}$=44.58	$\bar{x}$=18.94	$\bar{x}$=119.60	x=118.88
	s= 3.72	s= .48	s= 2.44	s= 2.29
4' - 10'	42.8	19.9	120.3	119.5
	35.1	19.6	116.1	115.4
	31.5	19.8	115.1	114.5
	32.4	18.9	117.4	116.6
	27.6	19.8	115.0	114.2
	$\bar{x}$=33.88	$\bar{x}$=19.60	$\bar{x}$=116.78	x=116.04
	s= 5.66	s= .41	s= 2.19	s= 2.15

TIME/TEMPERATURE CURING EFFECTS ON UNCONFINED COMPRESSIVE STRENGTH

Cured at 49°C (120°F) for 48 Hours Without Lime

Soil Depth	Unconfined Compressive Strength (psi)	Moisture Content (%)	Specimen Weight (Before) Curing (grams or pcf)	UNCT
10' - 19'	43.0	19.4	127.9	127.2
	38.4	19.0	125.0	124.2
	37.5	18.5	123.2	122.5
	39.1	19.2	122.8	122.0
	34.8	18.9	120.0	119.4
	$\bar{x}$=38.56	$\bar{x}$=19.00	$\bar{x}$=123.78	x=123.06
	s= 2.97	s= .34	s= 2.92	s= 2.88
19' - 28'	41.7	19.2	125.2	124.7
	33.4	18.4	117.6	116.8
	30.8	18.8	117.3	116.4
	38.2	19.3	120.3	119.8
	39.2	19.2	122.2	121.4
	$\bar{x}$=36.66	$\bar{x}$=18.98	$\bar{x}$=120.52	$\bar{x}$=119.82
	s= 4.45	s= .38	s= 3.30	x= 3.43

Appendix A

Sheet 2 - 7

TIME/TEMPERATURE CURING EFFECTS ON UNCONFINED COMPRESSIVE STRENGTH

Cured at 49°C (120°F) for 48 Hours With 6 Percent Lime

Soil Depth	Unconfined Compressive Strength (psi)	Moisture Content (%)	Specimen Weight (Before) Curing (grams or pcf)	Specimen Weight (Before) UNCT (grams or pcf)
3' - 4'	234.3	23.1	117.6	115.2
	421.8	23.8	116.6	113.4
	294.0	23.7	117.5	114.6
	564.0	23.2	117.7	110.2
	674.5	23.4	117.8	111. 4
	$\bar{x}$=437.72	$\bar{x}$=23.44	$\bar{x}$=117.44	$\bar{x}$=112.96
	s=183.23	s= .30	s= .48	s= 2.12
4' - 10'	166.7	20.0	117.7	110.7
	252.8	22.1	115.4	113.0
	641.6	22.0	115.7	111.7
	170.8	21.4	114.8	113.9
	166.9	21.4	114.8	113.9
	$\bar{x}$=279.76	$\bar{x}$=21.38	$\bar{x}$=114.48	x=112.64
	s=205.58	s= .84	s= 1.60	s= 1.41

TIME/TEMPERATURE CURING EFFECTS ON UNCONFINED COMPRESSIVE STRENGTH

Cured at 49°C (120°F) for 48 Hours With 6 Percent Lime

Soil Depth	Unconfined Compressive Strength (psi)	Moisture Content (%)	Specimen Weight (Before) Curing (grams or pcf)	UNCT
10' - 19'	469.5	20.9	120.5	117.7
	387.0	21.2	119.6	117.1
	624.0	20.2	119.0	115.7
	207.8	20.8	120.2	119.5
	205.4	20.9	118.8	117.9
	$\bar{x}$=378.74	$\bar{x}$=20.80	$\bar{x}$=119.62	$\bar{x}$=117.58
	s=178.69	s= .37	s= .74	s= 1.38
19' - 28'	412.5	20.8	117.5	114.9
	440.2	21.3	118.8	116.5
	275.2	21.5	118.5	115.9
	266.0	21.2	118.8	116.6
	478.0	22.1	118.2	113.2
	$\bar{x}$=374.38	$\bar{x}$=21.38	$\bar{x}$=118.36	$\bar{x}$=115.42
	s= 97.60	s= .48	s= .54	s= 1.41

TIME/TEMPERATURE CURING EFFECTS ON UNFONFINED COMPRESSIVE STRENGTH

Cured at 49°C (120°F) for 48 Hours With 6% Lime, 18% Fly-Ash, 1% Cement

Soil Depth	Unconfined Compressive Strength (psi)	Moisture Content (%)	Specimen Weight (Before) Curing (grams or pcf)	Specimen Weight (Before) UNCT (grams or pcf)
3' - 4'	275.4	19.6	118.4	117.4
	272.6	19.9	116.8	116.0
	273.2	19.5	117.1	116.4
	295.2	20.0	117.2	116.5
	270.6	20.1	117.5	116.7
	$\bar{x}$=277.42	$\bar{x}$=19.82	$\bar{x}$=117.40	$\bar{x}$=116.60
	s=10.09	s= .26	s= .61	s= .51
4' - 10'	246.8	19.8	115.6	114.9
	266.5	19.3	114.4	113.7
	262.5	20.0	114.8	114.1
	266.7	19.9	114.7	113.8
	246.8	19.2	114.4	113.7
	$\bar{x}$=257.86	$\bar{x}$=19.64	$\bar{x}$=114.78	$\bar{x}$=114.04
	s=10.23	s= .36	s= .49	s= .51

TIME/TEMPERATURE CURING EFFECTS ON UNCONFINED COMPRESSIVE STRENGTH

Cured at 49°C (120°F) for 48 Hours With 6% Lime, 18% Fly-Ash, 1% Cement

Soil Depth	Unconfined Compressive Strength (psi)	Moisture Content (1%)	Specimen Weight (Before) Curing (grams or pcf)	UNCT
10' - 19'	353.8	18.9	121.5	120.9
	309.1	18.9	118.9	118.2
	268.6	19.1	119.0	118.3
	319.7	19.2	121.1	120.5
	292.7	19.6	119.8	119.1
	$\bar{x}$=308.78	$\bar{x}$=19.14	$\bar{x}$=120.06	x=119.40
	s=31.70	s= .29	s= 1.19	s= 1.24
19' - 28'	266.7	17.1	118.9	118.1
	258.6	17.0	118.1	117.4
	218.6	17.1	115.6	113.9
	248.5	17.1	116.7	116.0
	260.4	17.6	116.1	115.1
	$\bar{x}$=250.56	$\bar{x}$=17.18	$\bar{x}$=117.08	x=116.10
	s= 19.02	s= .24	s= 1.38	s= 1.70

TIME/TEMPERATURE CURING EFFECTS ON UNCONFINED COMPRESSIVE STRENGTH

Cured at 49°C (120°F) for 48 Hours With 1.5% Lime

Soil	Unconfined Compressive Strength (psi)	Moisture Content (%)	Specimen Weight (Before) (grams or pcf) Curing	UNCT
4' - 10'	43.1	24.7	121.6	120.7
	41.6	24.7	121.1	120.1
	34.1	24.5	120.3	119.3
	37.2	24.7	119.6	118.5
	56.0	24.1	119.6	118.9
	$\bar{x}$=42.40	$\bar{x}$=24.54	$\bar{x}$=120.44	$\bar{x}$=119.50
	s=8.40	s= .26	s= .90	s= .89
10' - 19'	45.1	22.8	124.5	123.8
	55.3	22.1	123.7	122.9
	55.9	22.3	123.5	122.5
	46.0	22.2	124.4	123.5
	45.5	23.1	123.7	122.8
	$\bar{x}$=49.56	$\bar{x}$=22.50	$\bar{x}$=123.92	$\bar{x}$=123.10
	s=5.53	s= .43	s= .49	s= .53

APPENDIX B

PROJECT NO.: 59-083-002-000-1
COUNTY: Lowndes
NBL of I-65 "Before"

Sample No.	W(PCF)	d(PCF)	W(%)	qu(PSF)
2-A	121.9	99.1	23.1	6206
2-A	121.2	99.1	22.4	6013
2-B	121.3	99.9	21.5	3257
2-B	114.8	86.1	33.3	2769
2-B	112.6	83.6	34.6	2495
2-B	124.6	105.0	18.7	3588
2-C	114.8	89.3	28.4	3696
2-C	113.9	87.8	29.7	3997
2-D	119.4	97.0	23.1	6959
2-D	117.2	92.9	26.2	4104
2-D	120.4	99.5	21.0	3833
2-E	NO RUN SAMPLE WAS	CRACKED		
				$\bar{x}$=5446 s=4277

Appendix B

Sheet 1 - 4

PROJECT NO.: 59-083-002-000-1
COUNTY: Lowndes
NBL of I-65 "After"

Sample No.	W(PCF)	d(PCF)	W(%)	qu(PSF)
2-A	119.9	96.1	24.8	4971
2-A	121.9	98.5	23.8	6114
2-A	116.8	93.8	24.5	5232
2-A	122.5	101.2	21.0	4905
2-C	No RUN---SAMPLE FRACTURED			
2-D	112.4	86.2	30.4	1666
2-F	118.1	96.3	22.6	3254
2-F	118.0	95.4	23.7	3026
2-F	110.5	79.3	39.3	1513
2-G	110.0	81.0	34.8	2542
2-G	111.2	84.4	31.8	2942
2-G	125.5	108.5	15.7	3657
2-G	108.0	78.7	37.2	1958
2-H	111.1	85.4	30.1	2682
2-J	116.7	94.0	24.1	3658
2-J	115.5	92.5	24.9	2396
2-J	110.7	83.7	32.3	1816
2-K	NO RUN---SAMPLE HAD A LARGE PIECE OF WOOD IN IT.			
2-M	109.7	82.9	32.3	1906
2-M	108.3	82.6	31.1	2332
2-M	109.5	83.9	30.5	1959
2-N	NO RUN---SAMPLE TUBE BADLY BENT.			
				$\bar{x}$=3080
				s=1352

Appendix B

Sheet 2 - 4

PROJECT NO.: 59-083-002-000-1
COUNTY: Lowndes
NBL of I-65 "Before"

Sample No.	W(PCF)	d(PCF)	W(%)	qu(PSF)
1-A	119.1	95.8	24.3	6153
1-A	115.8	93.6	23.8	3075
1-A	117.9	98.5	19.7	2969
1-B	120.9	99.2	21.8	7444
1-B	119.4	97.9	21.9	5669
1-B	117.3	99.4	18.1	3955
1-C	124.7	105.7	17.9	21969
1-D	110.8	87.4	26.8	5717
1-D	110.2	87.1	26.6	4933
1-D	111.1	88.4	25.6	3111
1-E	122.1	103.8	17.7	3577
1-E	125.0	107.2	16.6	5667
1-F	118.6	98.8	20.0	4640
1-F	115.5	92.2	25.2	3570
1-F	122.5	102.7	19.2	3884
1-F	117.8	96.5	22.1	2976
1-F	116.1	93.1	24.8	2911
1-F	111.4	88.5	25.9	1236
1-G	120.2	104.5	15.1	14958
1-H	111.7	82.5	35.5	4540
1-H	116.0	91.3	27.1	5684
1-H	117.5	94.9	23.8	5487
1-I	120.1	97.2	23.5	5264
1-I	108.3	84.6	28.0	2317
1-J	116.1	93.6	24.0	3451
				$\bar{x}=4265$
				$s=1467$

Appendix B

Sheet 3 - 4

PROJECT NO.: 59-083-002-000-1
COUNTY: Lowndes
NBL of I-65 "After"

Sample No.	W(PCF)	d(PCF)	W(%)	qu(PSF)
1-C	117.2	94.4	24.2	4089
1-C	113.8	90.6	25.6	3948
1-F	112.4	86.5	29.9	1937
1-F	110.8	81.4	36.1	1432
1-F	107.8	76.8	40.4	1312
1-I	109.1	80.5	35.5	2170
1-I	107.1	79.8	35.1	1552
1-I	111.0	86.0	29.1	2707
1-I	112.9	85.8	31.6	1744
1-L	119.8	101.1	18.5	2582
1-L	119.8	97.5	22.9	2578
1-0	116.9	90.9	28.6	3176
1-0	116.1	93.0	24.8	3941
1-0	119.6	93.9	27.4	4035
1-0	118.4	92.7	27.7	4464
1-0	118.6	96.1	23.4	4373
1-R	111.4	83.5	33.4	2230
1-R	110.3	82.9	33.1	1358
				$\bar{x}$=2702
				s=1201

APPENDIX C

APPENDIX C

These specifications shall cover the materials and process to be used in a lime-fly ash-cement slurry pressure injection* of an embankment located at Milepost 143.6 of the northbound lane on Interstate 65 in Lowndes County.

1) The slurry shall consist of clean water, fly ash, hydrated lime, cement and surfactant, and shall be continuously agitated to insure uniformity of mixture.

2) The hydrated lime shall conform to the applicable parts of ASTM C207 Type N.

3) The fly ash shall conform to ASTM #C-618 Type C or a locally tested and approved source of Type F and the 1% Portland Cement shall be Type 1 Portland Cement.

4) A nonionic surfactant shall be used according to manufacturer's recommendations, but in no case less than 1 gallon per 3,500 gallons of water.

5) Spacing of the injections shall not exceed 2.5 feet on center each way, and the injections shall penetrate to approximate 20' depth on the top row of injections, and to a depth sufficient to reach 2' below the bottom of the slope on the middle and lower injection rows. One row of injections should be at the top of embankment adjacent to edge of pavement, one on a parallel bench about 1/3 down the embankment, and a third row of injections on a bench about 2/3 down the embankment. A double-injection procedure shall be used, the first one with injections 5' on centers and after 24-48 hours curing time offset 2'6" and inject the second injections. This procedure should be performed on all three levels.

6) Injection pressures shall be adjusted to disperse as large a volume of slurry as possible, within a pressure range of 50 to 200 psi.

7) A mix three parts of fly ash to one part of lime and 1% Portland cement shall be mixed to a specific gravity range of 1.24 - 1.27 and injected into the soil at 12" - 18" intervals.

8) Injection pipes shall penetrate into the soil in 12 to 18 inch intervals; injecting to refusal at each interval for a total top row depth of 20 feet or impenetrable material, whichever occurs first. The lower portion of the injection pipe shall consist of a hole pattern that will uniformly disperse the slurry throughout the entire depth.

9) Injections shall be continued to refusal, that is, until the maximum quantity of slurry has been injected into the soil, and the slurry is running freely at the surface out of previous injection holes or from areas where the surface soil has fractured.

10) The quantity of lime and fly ash injected shall be in the range of 14 to 18 pounds per square foot.

11) The Lime-Fly Ash-Cement Slurry pressure injection shall occur within 120 days of the issuance of this purchase order, but in no case shall the work occur between October 1 and the following April 1.

*Lime-Fly Ash-Cement Slurry Injection is a patented procedure of Woodbine Corporation. Reference U.S. Patent No. 4,084,381, April 18, 1978.

APPENDIX D

APPENDIX D

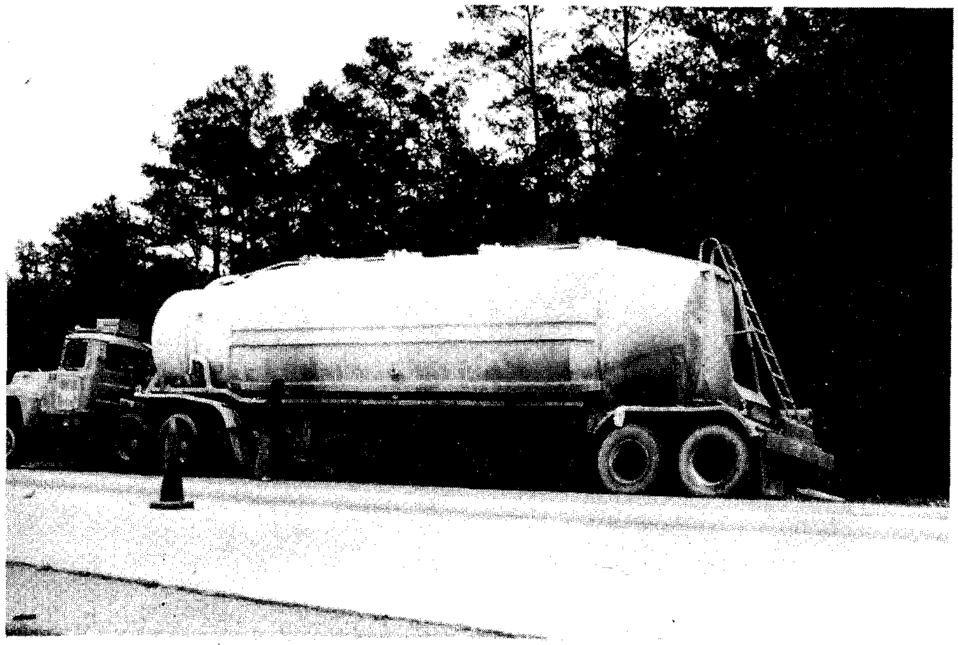


Photo 1 Lime and Fly-Ash hauled to jobsite in bulk and in the same tanker truck.

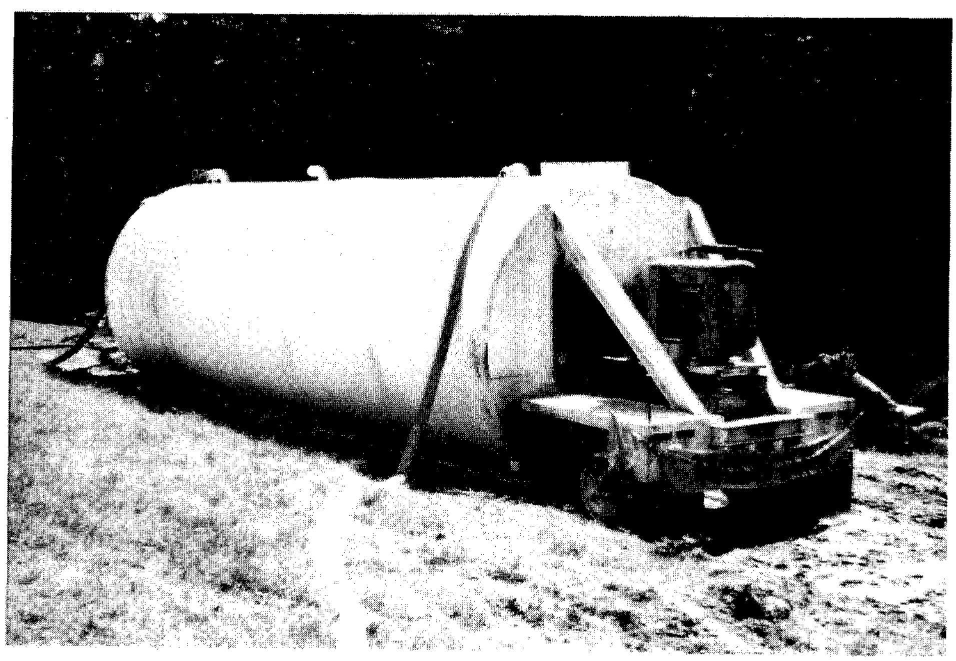


Photo 2 Lime and Fly-Ash pneumatically unloaded into Woodbine's 18,000 gal. mixing tank which was previously partially filled with water.

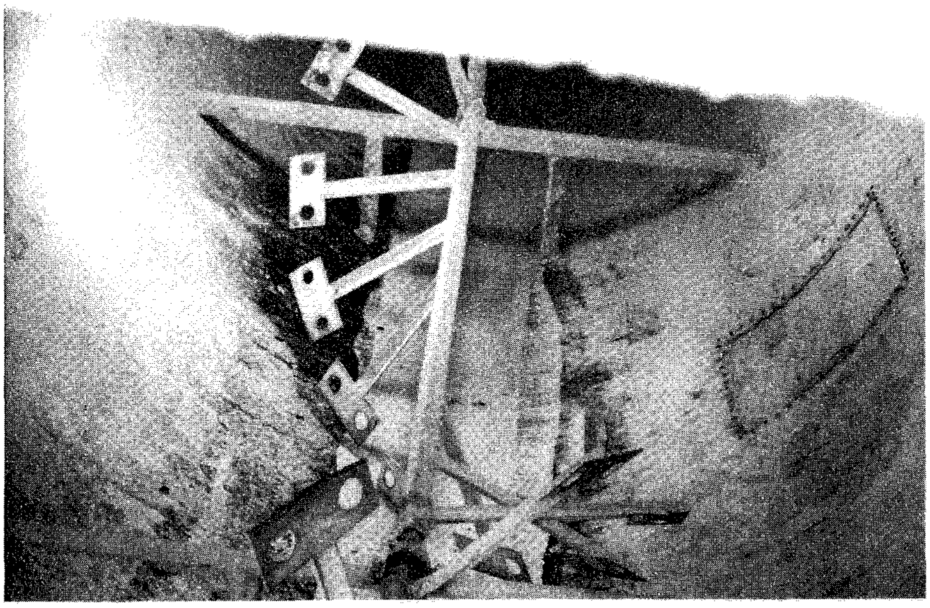


Photo 3 Paddles in mixing tank to keep solids in suspension.

Photo 4 Large rig primarily used as pumping station.

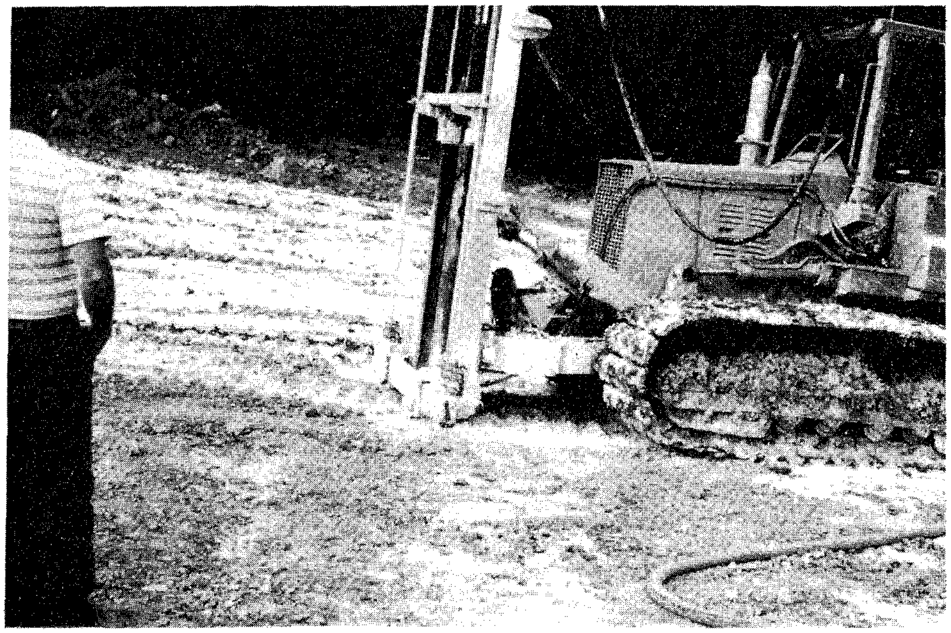


Photo 5 Tracked carrier used for injection along slope.

Photo 6 Eruption of slurry from ground approximately 50 feet from point of injection.

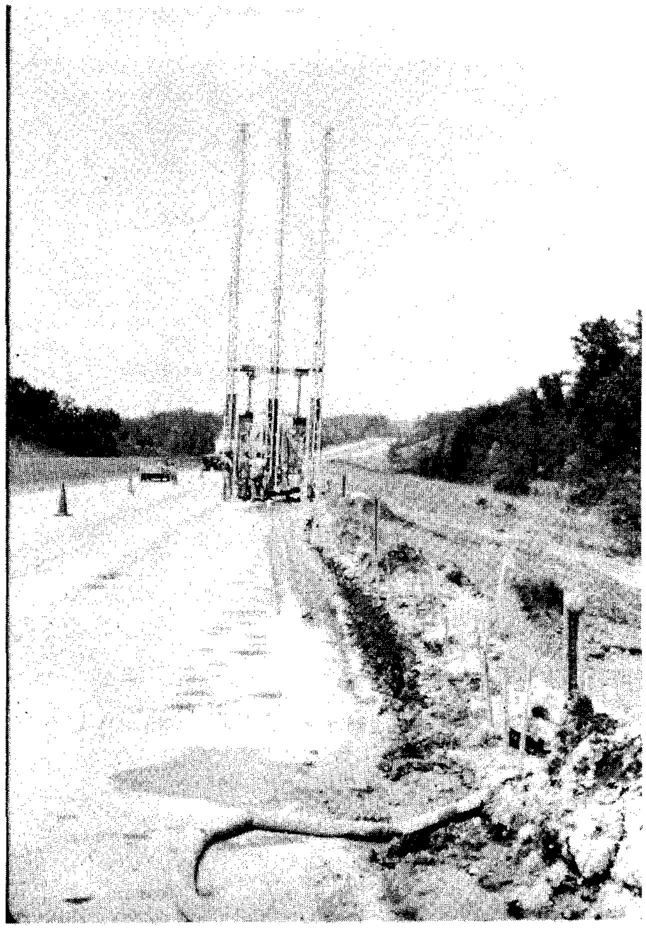


Photo 7 Injection of slurry with large rig at top of slope.

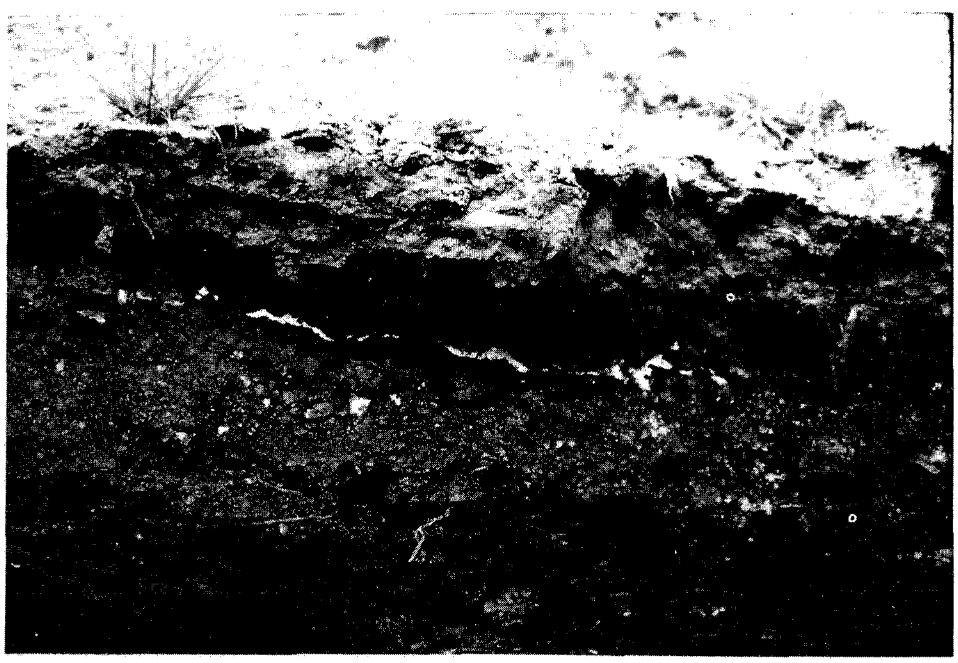


Photo 8 Sheet-like seam of slurry in an excavated face.

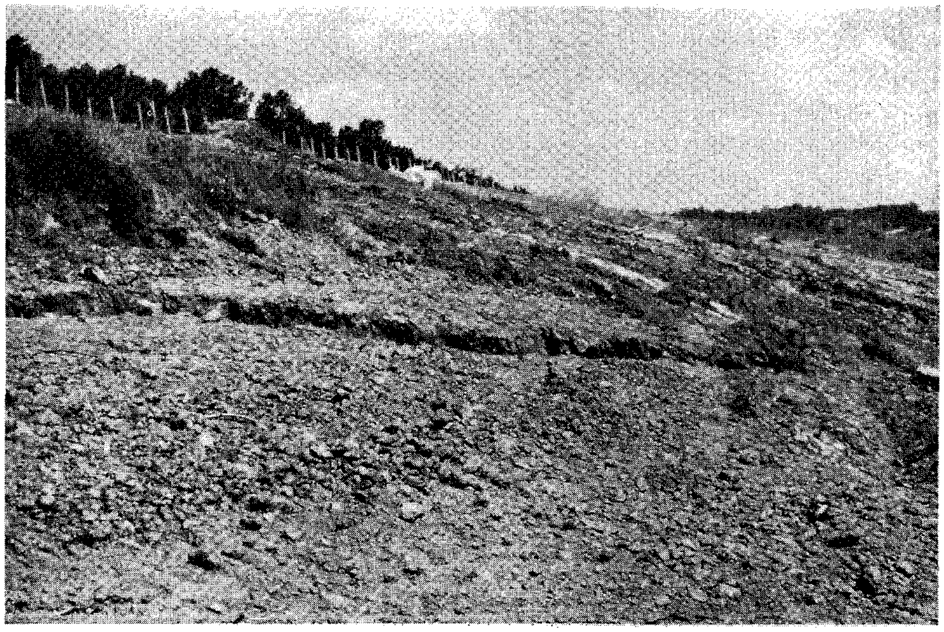


Photo 9 A small scarp developed during slope movement while slurry was being injected.

Photo 10 Same scarp, different view and after additional slurry was injected.

Photo 11 Rock Buttress and stream that roughly parallels the roadway.

Photo 12 Rock Buttress and slope completely reconstructed except for grassing.