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16. Abstract

This report summarizes the construction and initial evaluation of 12 full-scale test sites incorporating fly ash as a partial replacement for a) lime in subgrades and bases (8 sites), b) portland cement in concrete pavements (3 sites) and c) portland cement in a concrete box culvert (1 site). Each site consisted of several test sections of differing designs. Conclusions reached included 1) lime-fly ash stabilzation of clay type soils is effective and easily constructed, 2) replacing up to 25 percent of portland cement with high lime fly ash on a 1:1 basis resulted in no loss of strength nor any construction problems.

In addition to summarizing the construction and evaluation of the test sites, specific guidelines for construction of highways using fly ash are given.

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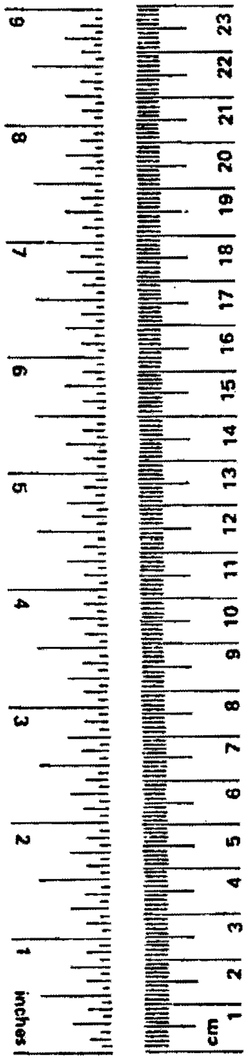
METRIC CONVERSION FACTORS

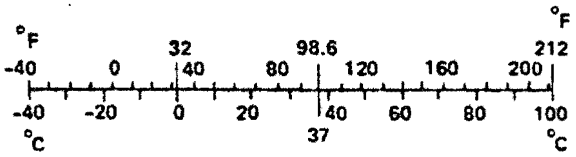
Approximate Conversions to Metric Measures

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		
in²	square inches	6.5	square centimeters	cm²
ft²	square feet	0.09	square meters	m²
yd²	square yards	0.8	square meters	m²
mi²	square miles	2.6	square kilometers	km²
	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
ft³	cubic feet	0.03	cubic meters	m³
yd³	cubic yards	0.76	cubic meters	m³
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



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		
cm²	square centimeters	0.16	square inches	in²
m²	square meters	1.2	square yards	yd²
km²	square kilometers	0.4	square miles	mi²
ha	hectares (10,000 m²)	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
m³	cubic meters	35	cubic feet	ft³
m³	cubic meters	1.3	cubic yards	yd³
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



*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.

CONSTRUCTION OF FLY ASH TEST SITES
and
GUIDELINES FOR CONSTRUCTION

by

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Research Report 240 - 2

Research Study 2-9-79-240

Sponsored by

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in cooperation with

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Texas Transportation Institute
Texas A&M University
College Station, Texas 77843

FOREWORD

The information contained herein was developed on Research study 2-9-79-240 titled "Fly Ash Experimental Projects" in a cooperative research program with the Texas State Department of Highways and Public Transportation and the U.S. Department of Transportation, Federal Highway Administration.

This is the second report on this study. The first report is: 240-1 "Analysis of Fly Ashes produced in Texas".

ACKNOWLEDGEMENTS

The authors wish to acknowledge the valuable assistance and support given by numerous people within the Department. In particular, Mr. Kenneth Hankins of the Planning and Research Division was responsible for obtaining all dynaflect, skid resistance, and texture measurements in the various test sites. Mr. Richard Magers of District 15 was instrumental in providing several projects which were used as experimental projects for the fly ash. He also provided valuable laboratory assistance. District 19 provided two test sites, with Mr. Sawyer Wimberly, Jr., designing the various test sections and Mr. John Betts performing laboratory evaluations. Mr. Leo Ledbetter of District 4, Mr. James Johnston of District 5, Mr. Ray Van Sickle, of the Houston Urban Office, Henley of District 18, and Mr. George Wall of District 25 each provided a construction project in which test sections were constructed. Constructing these test sections at the 12 test sites required a great deal of extra time and effort by District and Residency personnel. They were all enthusiastic and supportive of the research. Without their excellent support these test sites would not have been constructed.

The authors also owe a great deal to Mssrs Jose Saenz and Brian Stewart of TTI who carefully reviewed all the data and text and made sure the numbers were correct.

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1. INTRODUCTION

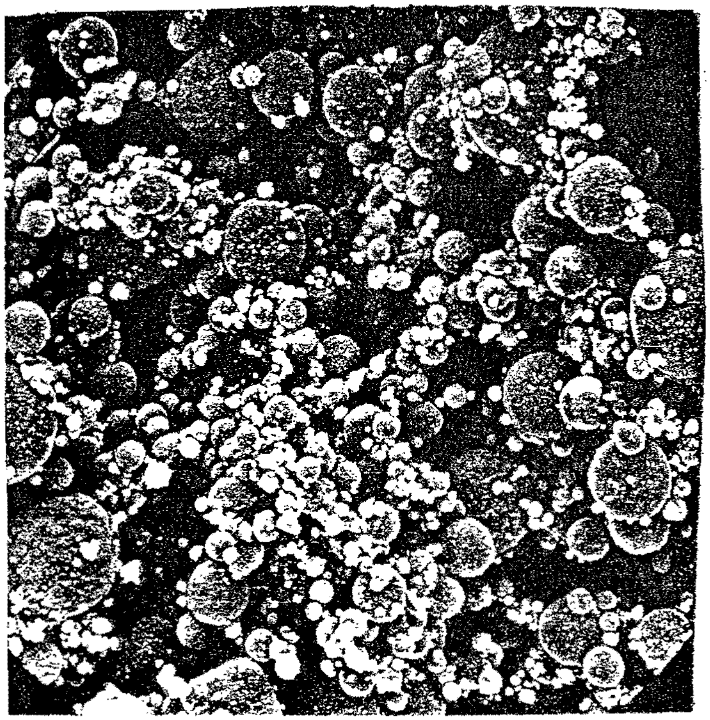
1.1 Background

Spiralling highway construction costs, coupled with decreasing revenues, are spurring the continuing development of more cost effective construction methods and materials. One set of materials being given serious consideration in Texas are local fuel ashes.

Fuel ashes are the by-products of coal-burning power generation plants, comprising the residual matter remaining after the coal combustion process, and categorized as either "fly ash" or "bottom ash." Fly ash constitutes the very fine particulate matter that escapes the combustion chamber with the fuel gasses (about 75% or more of which will pass the No. 200 sieve). These fly ashes are extracted from the gasses by various collection means and most are either stockpiled or stored in hoppers until disposal. Larger particles, on the other hand, fall to the bottom of the combustion chamber and are termed bottom ash (or slag).

The primary building blocks in fly ash are microscopic spherical granules composed mainly of silica, alumina, iron, and calcium oxides (Figures 1 and 2). Because fly ashes are the by-product of another process, chemical compositions vary both between plants and within a given plant with time. One major obstacle with fly ash use in construction today is this variability. The factors most influencing individual fly ash properties are (<u>1</u>):

1) Coal source
2) Degree of coal pulverization before combustion
3) Boiler unit design



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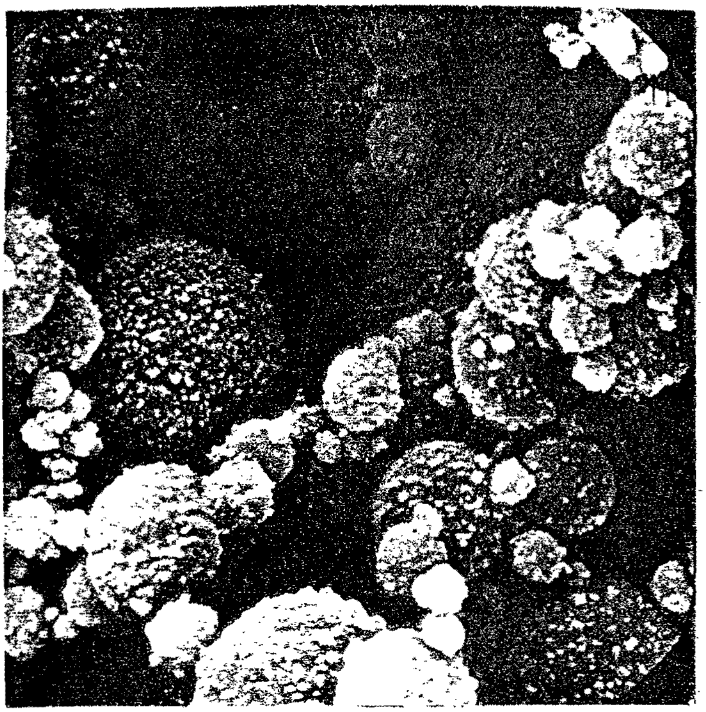

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Figure 1. Photomicrographs of Fly Ash from Sub-bituminous coal. (Wyoming)

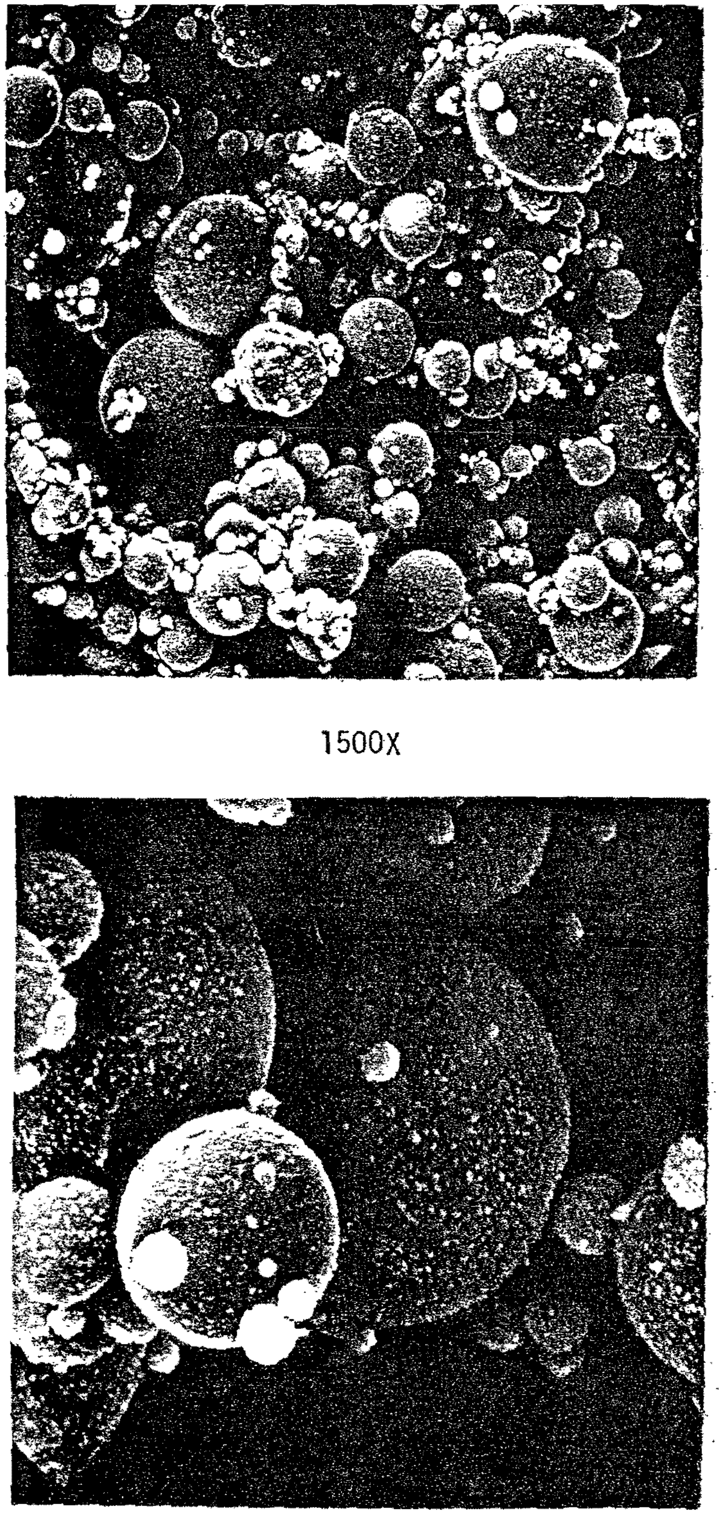

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Figure 2. Photomicrograph of Fly Ash from Lignite (Texas).

4) Loading and firing conditions
5) Fly ash collection methods
6) Storage methods

In Texas there are two general types of coal being burned, subbituminous coal and lignite. Their properties and chemistry are quite different and so are the properties of the resulting ashes. Complicating the picture further, neither subbituminous coal or lignite coal ashes are similar to the more commonly known forms of fuel ashes produced from bituminous coals. Thus, although there has been a significant amount of research and development work accomplished on bituminous coal ashes, which has culminated in the publication of some excellent reports (1,2), almost no information has been obtained on the properties and usefulness of subbituminous and lignite ashes.

On meeting this need, the variability in the fly ash has been the subject of a significant research effort on the part of the Texas Transportation Institute (TTI) and the Texas State Department of Highways and Public Transportation (SDHPT). While the results of this investigation are published in a separate report (Report 240-1)(3) and are not repeated in detail here, it should be pointed out that one main difference between the bituminous ashes and the subbituminous or lignite ashes is the amount of calcium oxide present in the ashes. Bituminous ashes generally are termed "low lime" ashes as their CaO content is usually less than around five percent. Subbituminous and lignite ashes, on the other hand, are often termed "high lime" ashes as their CaO contents range up to 30 percent. Naturally, as chemical compositions are different, behavior will also be different.

While dealing with chemical differences it should also be pointed out that the CaO contents of these "high lime" ashes are present in a combined state with silicates and aluminates, and - as such - are not "available" or "free" to react with other constituents. The amount of free lime (uncombined CaO) generally runs less than two percent, even though the total lime content will be up to 30 percent.

Fly ashes have been found to be satisfactory substitutes for 1) a portion of lime in soil stabilization and 2) a portion of portland cement in concrete. One major reason for this is the fact that many fly ashes are pozzolanic, which means that in the presence of moisture, the fly ash will react with $Ca(OH)_2$ present to form compounds possessing cementitious properties (calcium silicate and aluminate hydrates). In addition many of the western, or "high lime", fly ashes found in Texas also possess cementitious properties in themselves, which means they will react with water to form cementitious compounds similar to hydrated portland cement.

1.2 Lime-Fly Ash Stabilization

Lime-Fly ash stabilization, where a portion of the lime is replaced with fly ash, has been utilized successfully in many areas of the United States. In Texas a lime - fly ash - slag road was built near Rockdale in 1959 and has performed in a satisfactory manner for more than 20 years now, while being subjected to loads of up to 70,000 lb (4).

The strength and durability of lime-fly ash stabilized soils depend almost entirely on the quality of the pozzolanic reaction and resultant soil properties. Compaction, density, age, and the amounts of lime, silica, and alumina present determine to a very large degree the ultimate strength delivered in a pavement structure. The most critical factor influencing reactivity is small particle size; however, high temperature, low percentage of carbon, and proper moisture contents will also increase the reaction speed and consequently realize a quicker strength gain.

The pozzolanic reaction is slow, and in structures relying on it for strength, heavy loads must not be exerted during early life. Some DOT's are now building lime-fly ash stabilized highways and allowing them to "cure" for several months before use. The nonreactivity of fly ash in cold weather is also a prime reason for delayed use after construction.

If a load-induced failure does occur, fly ash has the unique capability to heal itself autogenously. This property is governed mainly by:

1) Age at failure
2) Degree of contact between cracked surfaces
3) Curing conditions (moisture, temperature, etc.)
4) Availability of the ongoing pozzolanic reactants

Because of autogenous healing, lime-fly ash mixtures have been proven less susceptible to deterioration and fatigue than other materials not possessing this property.

In stabilization of granular type soil, fly ash functions primarily as a pozzolan and filler of voids, and "floats" the coarser particles (greater than No. 4 sieve). With time and moisture a cementitious and pozzolanic reaction occurs forming a matrix which ultimately can develop unconfined compressive strengths as high as 3000 psi (more commonly between 500 and 1000 psi with 7 days cure at 100°F) (1).

In stabilization of clayey soils, the fly ash is helpful in working with lime to reduce the plasticity index of the clay. As the soil becomes more granular-like and workable, the pozzolanic reaction begins between the lime, and the silicates and aluminates. The degree to which lime-fly ash mixtures can improve a soil is a function of the soil mineralogy and fineness present.

The discussion thus far dealt with the low-lime fly ashes produced from bituminous coals. Interestingly, the newer high-lime fly ashes from subbituminous coals and some lignites possess cementitious properties in addition to pozzolanic properties. That is, high-lime fly ashes will generally react with water in a manner somewhat similar to portland cement, achieving significant unconfined compressive strengths. This cementitious reaction is very rapid with initial set times sometimes even faster than portland cement. To take advantage of this cementitious property, high-lime fly ashes should be <u>rapidly</u> mixed with the water and soil and compacted with a <u>minimum</u> of delay. The pozzolanic reactivity does not appear to be diminished by this additional property, but the long term interactive effects are not known, especially if it becomes cracked or is reworked after the cementitious reaction has occurred.

Recently in research by the State Department of Highways and Public Transportation (SDHPT), seven soils and two marginal base materials were tested with respect to lime-fly ash ratios, and the stabilization was found to be an acceptable construction procedure (4). The Texas study concluded that highways constructed with lime-fly ash stabilization have provided excellent performance, and that materials stabilized with them possess greater strengths than the same materials stabilized with either lime or fly ash alone. This report (4) outlined lab procedures for investigating strength characteristics of fly ash mixtures and recommended specifications for lime-fly ash treatment of materials in-place. It was finally suggested that all proposed highway construction and maintenance projects within economic haul distances of fly ash sources be seriously considered for lime-fly ash soil stabilization.

Specifications have been adopted by the American Society of Testing Materials (ASTM) governing the characteristics and properties of fly ash to be used in lime stabilization (ASTM C593) (5). Their guidelines set standards for the fineness and strength of lime-fly ash mixtures.

A Federal Highway Administration (FHWA) investigation recently found lime-fly ash mixtures superior to their straight lime counterparts when designed to be economically competitive (6). In addition, they presented guidelines outlining layer thickness design and lime-fly ash stabilization conditions.

1.3 Fly Ash-Portland Cement Concrete

The use of fly ash as a mineral admixture in portland cement concrete has steadily grown in popularity through the past 20 years. The vast majority of research has shown that the addition of fly ash in concrete mixes will (7,8,9):

1) Increase ultimate compressive and flexural strengths
2) Reduce segregation and bleeding
3) Reduce heat of hydration and volume change
4) Improve workability
5) Reduce alkalai-aggregate reactions
6) Increase sulfate resistance
7) Reduce mix costs

The first consideration of almost any concrete mix is strength, and it is almost axiomatic to say that the addition of fly ash will increase strength. The Water Tower Place Building, in Chicago, is the world's tallest reinforced concrete building (76 stories). One hundred pounds of fly ash per cubic yard of concrete was used in the foundations, walls, floors, and prestressed girders of this building. Nine thousand (9000) psi concrete was specified, and the Material Service Corporation noted that such a strength could not have been achieved without the use of fly ash (10).

Fly ash has also been used to partially replace portland cement. For a given compressive strength, fly ash may be added and the more expensive cement content reduced. A highway study in Kansas demonstrated that substitution of fly ash for 20% of the weight of cement reduced surface cracking and eliminated map cracking in portland cement concrete pavements (11). The accepted replacement of cement is more commonly between

10%-20% by weight, depending on the structural specifications, type of cement, and quality of fly ash.(8) The Federal Highway Administration now routinely accepts fly ash replacements of up to 15% of the portland cement in all concrete (12). ASTM has adopted a specification for both types of fly ashes as mineral admixtures for portland cement (13).

1.4 Objective

The study has as its objective the determination of the optimum utilization of Texas fuel ashes in stabilized subgrades, as a partial cement replacement in portland cement concrete pavement, and as a partial cement replacement in a structural concrete box culvert.

1.5 Scope

This report presents the construction details of twelve full scale test sites utilizing Texas Fly Ashes from subbituminous coals and lignites. Eight sites utilized lime-fly ash stabilization of soils, three sites utilized fly ash as partial replacement for portland cement in concrete pavements and one site involved fly ash in concrete box culverts. Each of the 12 test sites contained several test sections, including a control section. Following the construction details is a recommended guideline for highway construction utilizing fly ash.

2.0 Construction of Field Test Sites

2.1 General. The twelve test sites are located in various parts of Texas (Figure 3). A total of six different fly ashes were used (see Appendix B for summary of fly ash data). Pertinent data for all sites are summarized in Table 1, including the site, basic designs involved, and dates of construction.

Prior to construction, SDHPT District personnel performed laboratory investigations on all the proposed mixtures and established parameters for construction control. Each site was selected so that an adequate number of test sections could be constructed for evaluation. Test sections had to be long enough to get a "feel" for proper construction techniques and to properly evaluate under the action of weather and traffic. This translated into a minimum test section length of 800 ft (with the center 600 ft actually being evaluated). Maximum test section length varied as required for optimum contractor operations. In addition to fly ash test sections, each site had one control section, using accepted materials, for comparison purposes.

Test section layouts and typical sections, preliminary test section data, and construction equipment spreads are contained in Appendix A. A copy of the specifications used in the lime-fly ash stabilization test sites are given in Appendix C. The specifications used on all lime-fly ash projects was a final gradation requirement of 60% material passing the No. 4 sieve and a density requirement of 95% of laboratory density. The stabilization/cementing materials used included the six different fly ashes, Type A hydrated lime and Type I portland cement. Pertinent data for each site are presented in the following sections.

2.2 Lime-Fly Ash Stabilization Projects.

2.2.1 Test Site 1, FM 3378, Bowie Co. This project involved the

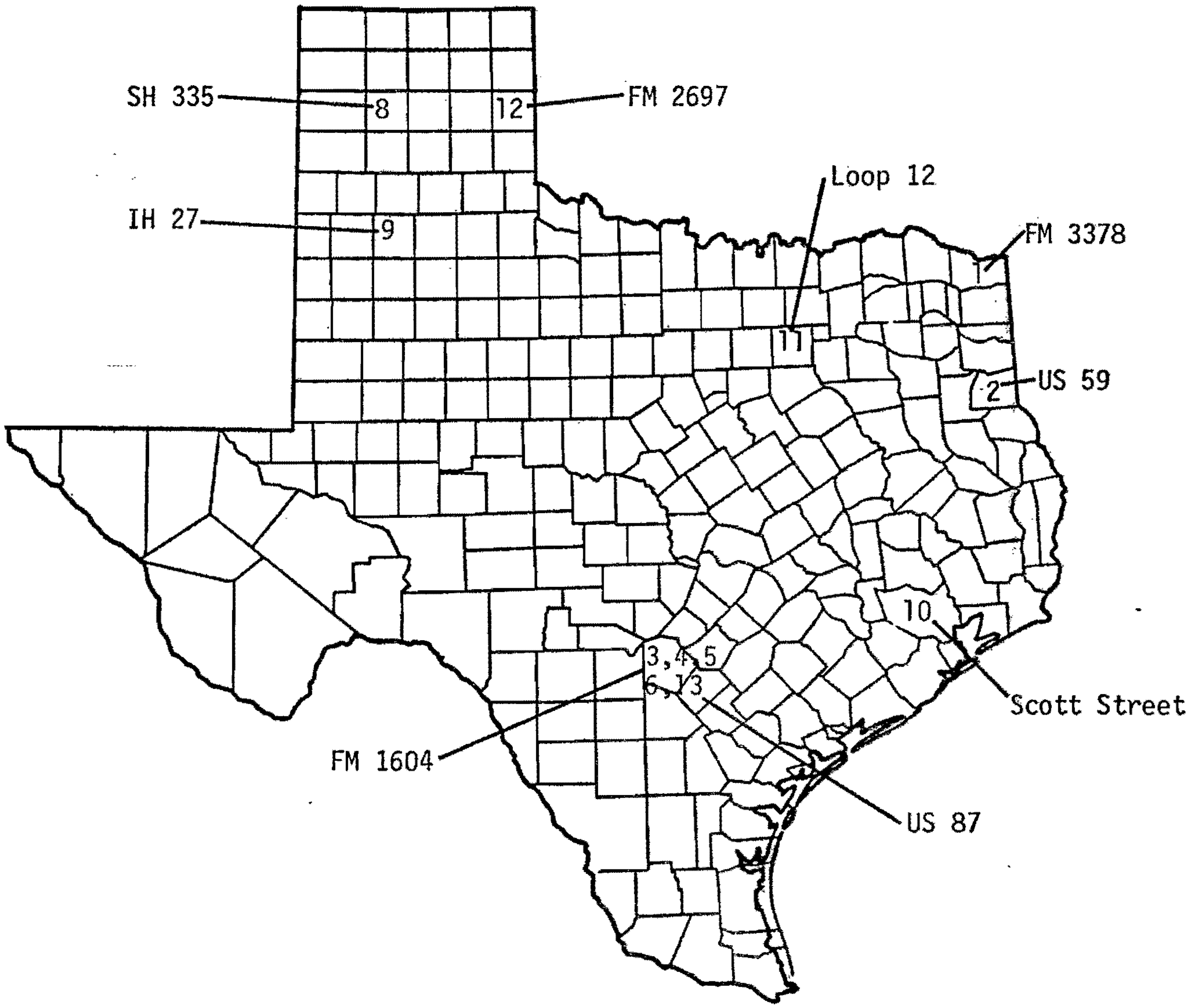

Figure 3. Locations of Fly Ash Test Sites in Texas

Table 1. Test Site Summary

Test Site[a] (County)	Highway Designation	Date Completed	Experimental Sections[b]	Fly Ash Source[c]
LIME-FLY ASH STABILIZED PROJECTS				
1(Bowie)	FM 3378	Oct, 1979	10-8/0(Control) 4/4,4/8,4/12, 6/0,6/6,6/12, 6/18,6/24,6/6	M
2(Panola)	US 59	Sept, 1979	10-4/0(Control) 2/4,2/8,4/8,4/4 0/22,2/24,2/16, 0/15,4/16	W
3(Bexar)	FM 1604	Dec, 1979	6-4/0(Control) 3/6,3/9,1½/5, 2/8,0/12	D
4(Bexar)	FM 1604	Oct, 1979	6-4/0(Control) 3/6,3/9,0/12, 1½/5,2/8	D
5(Bexar)	FM 1604	Mar, 1980	6-4/0(Control) 3/6,3/9,0/12, 2/8,1½/5	D
8(Potter)	SH 335	Mar, 1979	6-2½/0(Control) 2/4,2/6,2/8,3/6, 0/8	H
12(Wheeler)	FM 2697	Nov, 1979	5-0/20,0/30,0/40, 0/20,0/40	H
13(Wilson)	US 87	Apr, 1980	1-1½/6	D

Table 1. Test Site Summary (Continued)

Test Site[a] (County)	Highway Designation	Date Completed	Experimental Sections[b]	Fly Ash Source[c]
FLY ASH PORTLAND CEMENT CONCRETE PROJECTS				
9(Hale)	IH 27	July, 1980	4-0(Control), 15,20,25	
9(Hale) Replicate	IH 27	June, 1980	4-0(Control), 15,20,25	
10(Harris)	Scott St.	Aug, 1979	4-0(Control) 15,20,25	
11(Dallas)	Loop 12	Jan, 1980	4-0(Control), 15,20,25	B
FLY ASH PORTLAND CEMENT CONCRETE BOX CULVERTS				
6(Bexar)	FM 1604	July, 1979	4-0(Control), 15,20,25 on a 1.25 to 1 ratio	D

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[a] Test Site Numbers arbitrarily assigned and thus not in numerical order

[b] Number of test sections followed by design lime/fly ash ratios or weight percent replacement of portland cement by fly ash

[c] Fly ash characteristics are given in TTI Report 240-1 and summarized in Appendix B of this report.

construction of 10 test sections of lime-fly ash soil stabilization (16 in. thick) followed by a one-course bituminous surface treatment. The test sections used varying amounts of fly ash and lime to stabilize a low to medium plasticity index (PI) tan, silty clay soil. Test section layout, and typical section are given in Figures A-1 and A-2 (Appendix A).

The construction sequence consisted of first stabilizing the entire 16 in. layer with either 4 percent hydrated lime or 6 percent fly ash from plant M. This was accomplished during the period from September 5, 1979 (Test Section 1) through September 14, 1979 (Test Section 10).

The initial 16 in. deep treatment of soil was performed with two separate applications of lime (or fly ash) in 10 and 6 in. lifts. Six in. of material were bladed from the east bound lane onto the other lane and the bottom 10 in. to be treated were ripped by a motor grader. Hydrated lime was applied dry at a rate of 28.9 lb/yd^2 (to achieve a weight percentage of 4.0), then slightly watered to control dust, and initially mixed. The area treated was allowed to cure for three days, after which final mixing of the treated soil began by using a road mixer. After the gradation requirement of 60% passing a No. 4 sieve was achieved the area was watered to optimum moisture (approximately 16%) and compacted. The compactive effort was applied by using a Rex tamping roller, with an Ingram pneumatic roller applied to seal the surface. The same procedure was applied when deep treating the second half of the west bound lane. After the lower 10 in. deep treatment with lime was completed, the excess soil was bladed back into place and shaped. Following this, the upper 8 in. were stabilized, of which 2 in. had to be reworked. Additional amounts of lime and/or fly ash were added (See Table A-1 in Appendix A for the equipment spread). Soil properties, final stabilization dates and construction control data for each test section are given in Table 2.

Table 2. Lime-Fly Ash Stabilization Data for Test Site 1 (FM 3378 in Bowie County), RS 1203(2)A.

Test Section No.	Base Lime/Fly Ash % (by wt.) Design/Actual		Date of Construction	Plasticity Index (PI)	Final % Passing No. 4 Sieve[a]	Moisture Content[a] (%)	Field Density (lb/ft^3)	Percent of Laboratory Density[b]
1	8/0	8.1/0.0	9/17/79	18	73	17	110	101
2	4/4	3.8/4.0	9/17/79	--	63	15	109	99
3	4/8	3.8/8.2	9/17/79	19	70	14	112	96
4	4/12	3.4/15.1	9/25/79	--	81	11	108	95
5	6/0	7.4/0.0	9/25/79	17	68	14	109	96
6	6/6	5.4/5.8[c]	9/26/79	--	73	14	109	97
7	6/12	5.7/11.4[c]	9/26/79	13	77	13	111	97
8	6/18	6.9/17.8[c]	9/27/79	--	78	14	109	96
9	6/24	5.3/23.2[c]	9/28/79	14	78	14	113	100
10	6/0	5.7/5.4[c]	9/27/79	--	84	13	114	100

[a] Average of three or four measurements

[b] As determined by Test Method Tex-114-E

[c] The effective percentage of fly ash may be about 6 percent lower due to the loss of cementitious action between the fly ash and existing materials, since the top 8 in. of the 16 in. previously stabilized lift was reworked in order to add more fly ash.

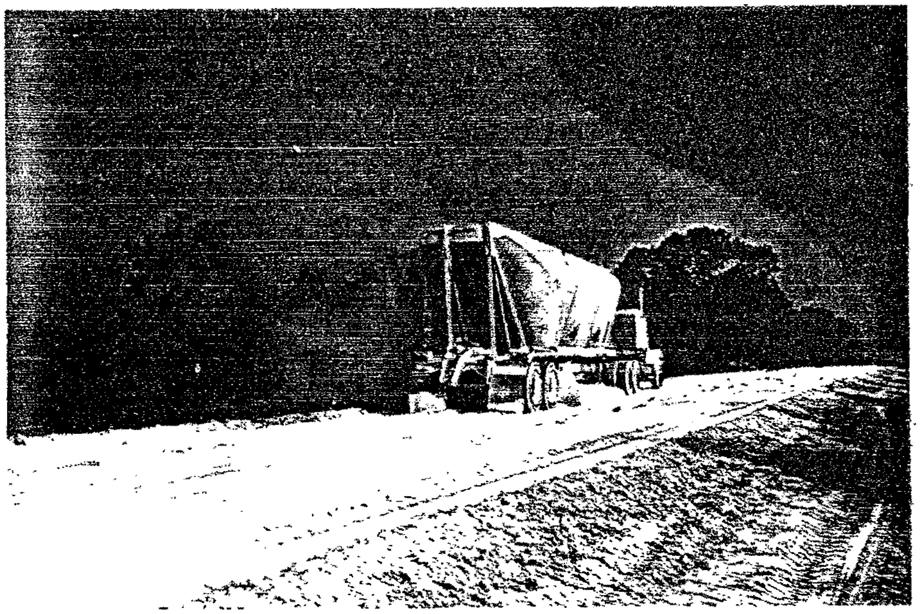

Figure 4. Cement Transport Trucks used in the application of Fly Ash on FM 3378 in Texarkana, Texas (Test Site No. 1)

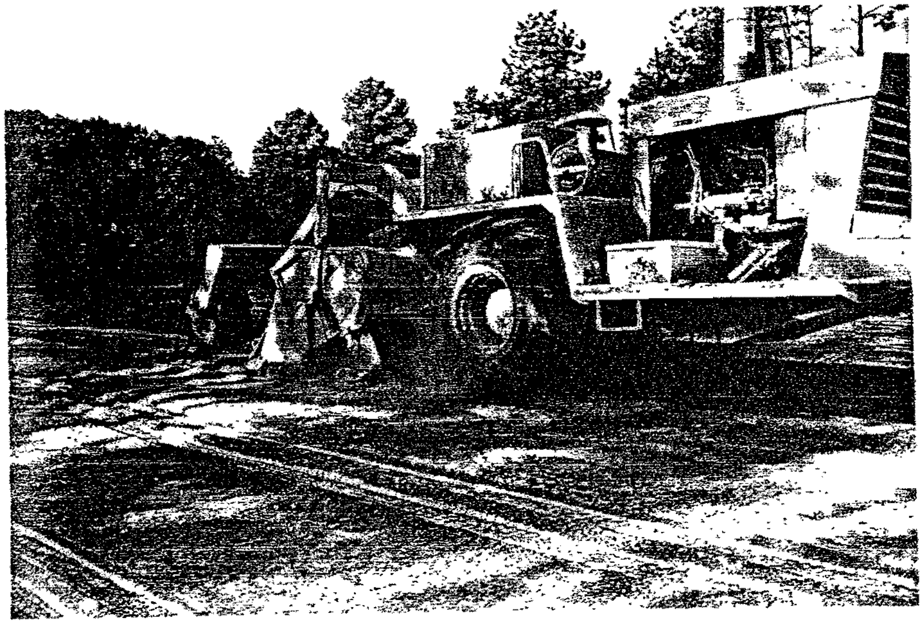

Figure 5. Rex Mixer used in Deep Treatment of Fly Ash on FM 3378 Texarkana, Texas (Test Site No. 1)

Because of the reworking of previously stablized fly ash material, any strength resulting from cementitious reactions between the fly ash and the water present may have been largely lost. Pozzolanic reactions between the fly ash, lime, and clay would probably not have been damaged. The lime was placed dry, then slightly watered, and initially mixed. It was allowed to cure for three days, then final mixed and sealed with a pneumatic roller.

In deep treating the fly ash sections, a Rex road mixer, capable of mixing the full 16 in., was used. Fly ash was transported to the job site in cement transport trucks (Figure 4) with loads ranging from 23 to 25 tons. Due to the fact that the soil had not been cured with lime it was feared the fly ash would not be able to help in breaking down the larger clay particles to help meet gradation requirements. Unlike with deep treatment of lime, there was not to be a 3 day curing peiod, instead the contractor was allowed 6 hours to have 10 in. of the fly ash treated subbase material watered, mixed, and compacted. Gradation was easy to obtain, probably because the temperature of the fly ash (approx. 120 F.) somewhat dried out the clay portion of the area treated. The fly ash was forced out of the trucks at a pressure of 1 to 3 psi. Due to the low pressure when placing the fly ash, dust was not a major problem. After the fly ash had been placed on the ground it was initially mixed the full 16 in. with a Rex road mixer (Figure 5). After 2 or 3 passes gradation was obtained (60% passing a No. 4 sieve), and the top 6 in. of material bladed off to the side. Water was added to the bottom 10 in. of fly ash treated soil to achieve optimum moisture and mixed. After mixing, compaction was begun using a Rex tamping roller. This compactive effort was applied until it was estimated that at least 95% density had been obtained. Next the surface was sealed with a pneumatic roller. The top 6 in. of original subbase material that had been previously bladed off was shaped back into the roadway and sealed with a pneumatic roller until time to place additional lime and/or fly ash for the different test sections. No immediate problems occurred with mixing fly ash 16 in. deep.

Placement of fly ash in the top 8 in. of the subbase test sections did not begin until the total amount of lime required in each test section had been placed, mixed, and allowed to cure for at least 3 days. As before, the fly ash was placed by cement transport trucks on the area to be treated after the area had been previously ripped to a depth of 8 in. once the fly ash was spread out, initial mixing of the material was obtained by use of a road mixer. After gradation was obtained water was added until optimum moisture was reached, at which time final mixing, compaction, sealing, and cutting to the required elevation were accomplished. Approximately 4 hours were required to process two test sections (3400 yd^2) as described above.

The construction of these 10 test sections proceeded without any significant problems. Proper gradation, intimate mixing, optimum moisture, and compaction density were all easily obtained. To take advantage of the cementitious properties of the fly ash (in addition to its pozzolanic properties) each test section had to be finished the same day it was started and this was accomplished within a six-hour period.

2.2.2 Test Site 2, U S 59, Panola Co. This test site consisted of 8 in. of lime-fly ash stabilized subgrade, covered by a 12 in. flexible base and a one course surface treatment. The project involved widening an existing facility. A typical section of the project is shown in Figure A-3 (Appendix A). Ten test sections of a low PI tan silty clay (with sand) were stabilized using different amounts of lime and fly ash. These sections were constructed on the outside southbound lane (Figure A-4 in Appendix A). Figure 6 is a photograph of the actual test site showing the space restrictions placed upon the contractor. Table 3 shows pertinent soil data along with actual quantities of lime and fly ash placed in each test section. The construction equipment used in this project can be found in Table A-2 (Appendix A). Fly ash came from plant W.

Lime was applied in a dry form directly over the soil which had been previously ripped out by a motor grader. After the lime was placed, mixing began and continued until adequate mixing of soil and lime was assured. Compaction was accomplished by the sheepfoot roller. Water wagons applied water daily to keep the soil from drying.

To insure initial clay breakdown from the action of lime, the fly ash was not placed until approximately three days had elapsed after application of lime. Before any fly-ash was placed, road mixers pulverized the soil until a minimum of 60% passed the No. 4 sieve. Once the required gradation was obtained, fly ash was applied directly on the area to be treated by transport trucks pulled by a motor grader. The fly ash transport trucks were pulled to insure a uniform rate of application and to prevent their becoming stuck in the loosened soil. Due to the construction area being sheltered from winds, dusting was only a minor problem but, as a precaution, traffic was stopped while fly ash

Table 3. Lime-Fly Ash Stabilization Data for Test Site No. 2 (US 59 in Panola County)

Test Section No.	Final Lime/ Fly Ash % (by wt.) Design/Actual		Date of Construction	Plasticity Index (PI)	Final % Passing No. 4 Sieve[a]	Moisture Content[a] (%)	Field Density[a] (lb/ft^3)	Percent of Laboratory Density[b]
1	4/0	4.2/0.0	7/10/79	15	67	11.0	111.0	97.2
2	2/4	2.0/3.3	7/12/79	--	78	10.4	112.1	97.8
3	2/8	1.9/9.8	7/20/79	7	89	8.0	111.2	97.1
4	4/8	3.9/8.2	7/23/79	--	84	8.4	112.1	99.0
5	4/16	3.7/15.3	7/24/79	18	70	14.0	108.0	93.3
6	0/15	0.0/15.9	8/02/79	--	74	9.7	111.8	97.5
7	2/24	1.9/23.9	8/09/79	6	82	10.0	111.2	95.0
8	2/16	1.9/14.4	8/14/79	--	90	10.3	110.7	95.4
9	0/22	0.0/20.8	8/16/79	--	80	8.5	106.1	92.2
10	4/4	3.7/4.2	8/18/79	19	76	11.7	110.9	95.4

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[a] Average of three or four measurements

[b]

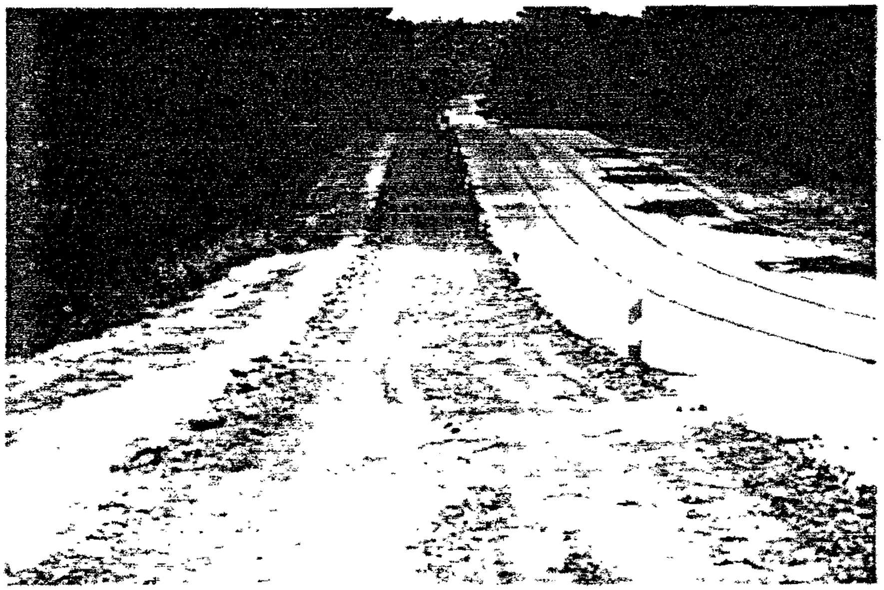


Figure 6 . Project Site on US 59 in Carthage, Texas.
(Test Site No. 2)

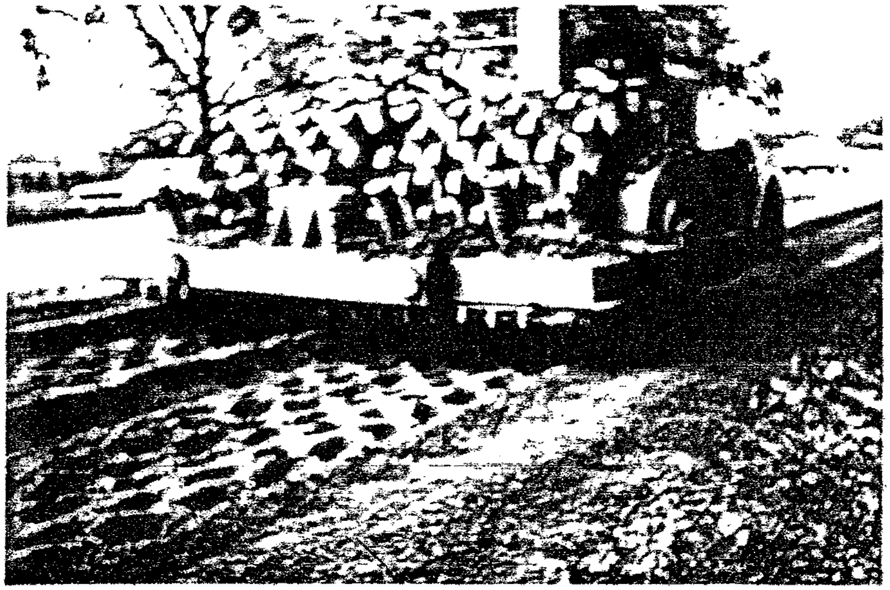


Figure 7 . Sheepsfoot Rolling for Compaction on US 59 in Carthage, Texas (Test Site No. 2)

was being applied. Before initial mixing, a motor grader bladed the material next to the existing road into the center of the working area. After proper initial mixing, water was added and final mixing begun. After final mixing the material was bladed evenly along the roadway. Compaction by sheepsfoot roller ensued with water added to maintain optimum moisture. Approximately 8 complete passes of a sheepsfoot roller was needed to obtain 95% of laboratory density (Figure 7). The area was sealed by 3 passes of a pneumatic roller. Only one test section could be processed in any one day due to the space limitations of this project.

As with the previous site, care was exercised to insure the fly ash was added, watered, mixed and compacted within a four hour period. Even with the site restrictions this posed no significant problems to the contractor and the required densities were easily obtained.

2.2.3 Test Site 3, FM 1604, Bexar County. This lime fly ash stabilization test site is located on the west bound lanes of FM 1604 and consists of six test sections of six in. lime fly ash stabilization of a tan, low PI clay silt covered by 10 in. of flexible base and a two course surface treatment. Each test section is approximately 800 ft long using varying amounts of fly ash and lime. There are transition sections of varying lengths between test sections. The complete test site was constructed from December 7, 1979 to December 14, 1979. Figure A-5 shows the layout of the different test sections and Figure A-6 gives a typical section of this project (Appendix A). Table A-3 in Appendix A summarizes the equipment use.

The lime portion of this stabilization was constructed using the standard dry method. After a curing period of three days, water was added and additional passes of the road mixer were made. When the soil appeared to have approximately 50% passing a No. 4 sieve, mixing was stopped and compaction of the lime-soil began. Once sufficiently compacted, the area was sealed by a pnuematic roller. Prior to the addition of fly ash, the lime treated soil was ripped out by a motor grader and pulverization began by use of road mixers. This pulverization was continued until the proper gradation of 60 percent passing a No. 4 sieve was obtained, at which time fly ash was added to the lime treated soil. The fly ash came from plant D.

Fly ash was delivered to the job site in 25 ton loads by means of transport trucks and applied directly from the transport truck to the area to be treated. Due to the loose soil, the transport trucks were pulled by a motor patrol to insure uniform distribution. Dusting was considered to be a problem and a canvas "tent" was fabricated to reduce this problem.

The mixing of fly ash with the subgrade material in any test section did not begin until all the fly ash was placed. Because of the fast set time of fly ash, water was not added to control dusting; instead a disk plow was used in the treated area to "pre mix" the fly ash-soil. If this had not been done, the mixer operators would have been engulfed in a fly ash cloud on the first pass. After initial mixing, all the treated soil was bladed away from the roadway and a pneumatic roller was applied to compact the soil below. Next, half of the treated soil was bladed back into place, watered to optimum moisture (around 17%), and compacted using a hyster compactor. To seal the bottom half of the subgrade it was compacted with a pnuematic roller. This process was repeated for the top half of the subgrade. Compaction in two lifts was performed to insure 95% of laboratory density. Approximately 10 hours were required to place and compact one test section (6,000 yd^2) of lime-fly ash stabilized soil, but only three hours elapsed after water was first applied to the fly ash until compaction was completed. This procedure was followed throughout to maximize the benefits of cemetitious chemical action of the fly ash. Table 4 summarizes the percentages of lime and fly ash placed in the test sections, along with pertinent soil data.

As the personnel in this District began using this fly ash several years ago, they provided the most detailed information about the construction procedures to be followed in constructing all the test sites. SDHPT and contractor personnel were all well acquainted with fly ash and knew how to achieve optimum results in the minimum amount of time.

Table 4. Lime-Fly Ash Stabilization Data for Test Site 3
(FM 1604 in Bexar County) RS 1855(6)

Test Section No.	Final Lime/ Fly Ash % (by wt.) Design/Actual	Date of Construction	Plasticity Index (PI)	Final % Passing No. 4 Sieve[a]	Moisture Content[a] (%)	Field Density[a] (lb/ft^3)	Percent of Laboratory Density[b]
1	3/6 3.0/6.3	Dec. 1979	11	72.3	17.3	107.7	99.6
2	3/9 3.2/10.0	Dec. 1979	20	72.3	16.6	100.6	93.2
3	1.5/5 1.5/5.0	Dec. 1979	12	81.0	9.9	109.0	92.5
4	4/0 3.7/0 (control)	Dec. 1979	23	67.7	9.4	112.2	100.8
5	2/8 1.9/7.8	Dec. 1979	22	64.1	7.8	113.3	99.6
6	0/12 0/11.6	Dec. 1979	5	60.5	7.1	116.4	97.2

[a] Average of three or four measurements

[b] Determined by Test Method Tex-114-E

2.2.4 Test Site 4, FM 1604, Bexar Co. This project involved the construction of six test sections of lime-fly ash subgrade (6 in.) stabilization of a low PI clay silt, covered by 14 in. of flexible base and a two course surface treatment. Each test section was approximately 800 ft long with 100 ft transition sections and was stabilized with various amounts of fly ash and lime. The test site portion was constructed from July 17, 1979 to October 28, 1979. A typical section and layout of the test sections can be found in Appendix A (Figures A-7, A-8) along with a list of the equipment used by the contractor (Table A-4).

The lime portion of this stabilization process was constructed using the standard dry method. Truck loads of 25 tons were placed directly on the already pulverized soil. After the lime was placed, the treated soil was repulverized by one pass of a road mixer and left to cure for three days. After this waiting period, water was added and additional passes of the road mixer were made. When the soil appeared to have approximately 50% passing a No. 4 sieve, mixing was stopped and compaction of the lime-soil began. Once sufficiently compacted, the surface was sealed by pneumatic rollers. Prior to addition of fly ash, the lime-treated soil was ripped out by motor graders and pulverized again by use of road mixers. The pulverization was continued until the proper gradation of 60 percent passing a No. 4 sieve was obtained, at which time fly ash was added to the lime-treated soil.

Fly ash was delivered to the job site in 25 ton loads by means of transport trucks and applied directly from the transport truck to the area to be treated (Figures 8 and 9). Due to the loose soil, the transport trucks were pulled by a motor patrol to insure uniform distribution. Due to moderate winds, dusting was again considered to be a problem and a canvas

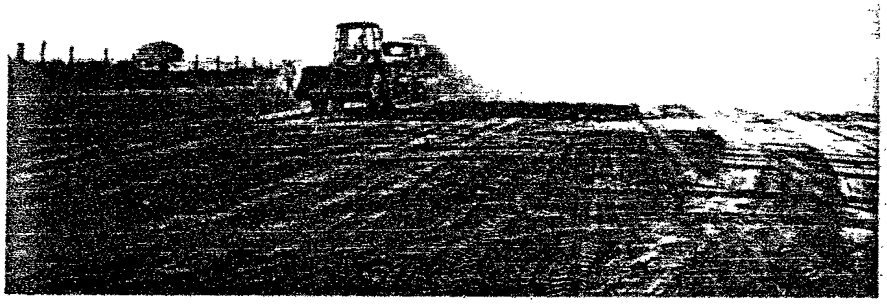


Figure 8. Application of Fly Ash by Transport Truck on FM 1604 in San Antonio, TX. (Test Site No. 4)

Figure 9. Close up of Fly Ash after first pass of Transport Truck on FM 1604 in San Antonio, TX (Test Site No. 4)

"tent" was fabricated to reduce this problem (Figure 10). Wh e fly ash was discharged under pressure (10 psi), there was no noticeab duction in the effect of dusting from the tent (Figure 11); however, duced pressures dusting appeared to be less of a problem. At lower sures the time for application of ash increased significantly and t ses would clog; therefore, the ash was applied at the higher pressure t hout the remainder of the project.

The mixing of fly ash with the subgrade material in any section did not begin until all the fly ash was placed. Because of t st set times of fly ash, water was not added to control dusting; ins a disk plow was used in the treated area to 'pre mix' the fly ash-soil. If this had not been done, the mixer operators would have been engulfed in a fly ash cloud on the first pass. A slight amount of dusting still occurred as can be seen in Figure 12 (Note the mask worn by the operator)! After initial mixing, all the treated soil was bladed away from the roadway and a pneumatic roller compacted the soil below. Next, half of the treated soil was bladed back into place, watered to optimum moisture (around 17%) and compacted using a hyster compactor. To seal the bottom half of the subgrade, it was compacted with a pneumatic roller. This process was repeated for the top half of the subgrade. Compaction in two lifts was performed to insure a minimum of 95% of laboratory density. Approximately 10 hours were required to place and compact about 6000 yd^2 (on a test section) of lime-fly ash stabilized soil but only three hours elapsed after water was first applied to the fly ash until compaction was complete. This procedure was followed to maximize the benefits to cementitious chemical action. Table 5 summarizes the actual percentages of lime and fly ash placed in the test sections, along with pertinent soil data.

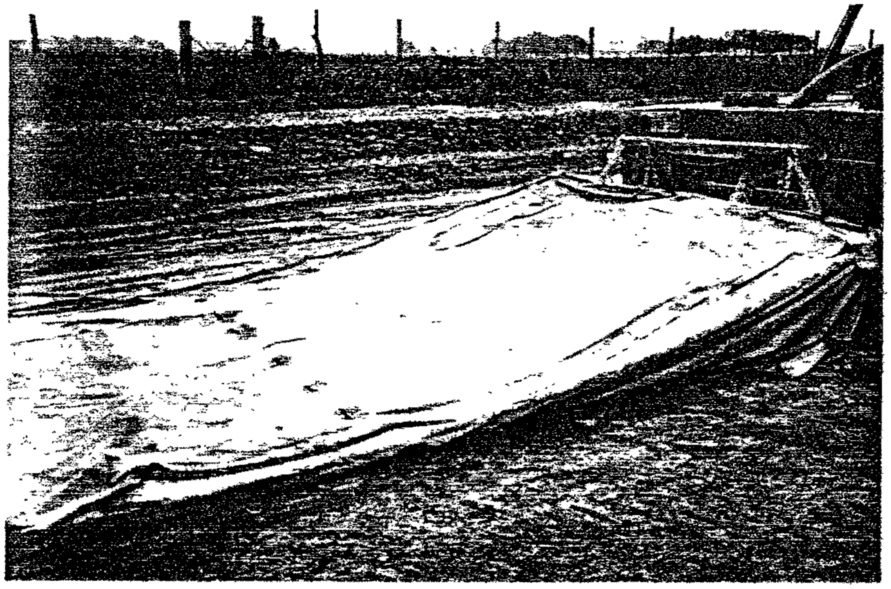


Figure 10. Canvas "Tent" used in attempt to Reduce Dusting on FM 1604 in San Antonio, TX. (Test Site No. 4)

Figure 11. Results of Attempt to Control Dusting with the Canvas "Tent" on FM 1604 in San Antonio, TX. (Test Site No. 4)

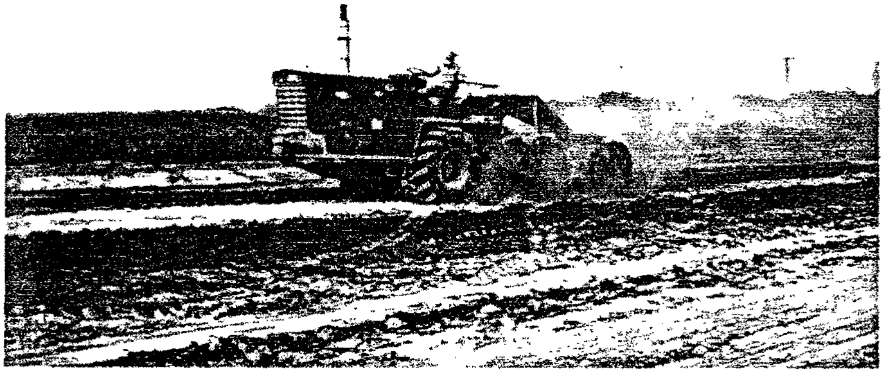


Figure 12. Initial Mixing of Fly Ash Treated Soil on FM 1604
in San Antonio, TX (Test Site No. 4)

Table 5. Lime-Fly Ash Stabilization Data for Test Site 4 (FM 1604 in Bexar County) (RS 1855(7))

Test Section No.	Final Lime/ Fly Ash % (by wt.) Design/Actual		Date of Construction	Plasticity Index (PI)	Final % Passing No. 4 Sieve[a]	Moisture Content[a](%)	Field Density[a] (lb/ft^3)	Percent of Laboratory Density[b]
1	4/0 (control)	4.1/0	Aug. 1979	27	70.1	16.2	109.1	95.3
2	3/6	2.8/5.6	Oct. 1979	22	68.0	13.0	104.1	95.2
3	3/9	2.9/9.1	July 1979	20	68.2	22.8	104.3	95.3
4	0/12	0/9.8	July 1979	8	81.1	11.3	112.4	93.4
5	1½/5	1.4/4.8	July 1979	15	71.4	12.3	104.8	93.4
6	2/8	1.9/7.6	Aug. 1979	18	68.5	20.1	103.4	99.6

[a] Average of three or four measurements

[b] As determined by test method Tex-114-E

Two construction related problems were uncovered during the construction of this test site. First, fly ash being dispensed through a pneumatic hose under moderate pressures of 10 psi from a transport truck resulted in considerable dusting even though attempts were made to minimize the problem with canvas tents. Second, reducing air pressure minimized the dusting problem but caused some line clogging and slowing of operations. Thus, the conclusion is that a manifold and spray assembly needs to be designed to handle the fly ash. If fly ash were utilized throughout a given project the cost of designing and installing such an assembly would be negligible and should pose no significant problem to a contractor.

2.2.5 Test Site 5, FM 1604, Bexar Co. This lime fly ash stabilization test site is located on the west bound lane of FM 1604 between the San Antonio river and Elmendorf and involved the stabilization of six in. of a tan, low PI, clayey silt subgrade material covered with 12 in. of flexible base and a two course surface treatment. Each test section is approximately 800 feet long with 100 ft. transition sections between each other, and was stabilized with various amounts of lime and fly ash (From Plant D). The test sections were constructed during the period from March 12, 1980 to April 21, 1980. In Appendix A, a typical section layout of test sections and contractors equipment are given (Figures A-9 and A-10, Table A-5).

The lime portion of the stabilization was constructed using the standard dry method. Three days following the placing and initial mixing of the lime, additional mixing was performed with the road mixer. When the soil appeared to have approximately 50% passing a No. 4 sieve, mixing was stopped and compaction of the lime-soil began. Once sufficiently compacted, the surface was sealed by pneumatic rollers. Prior to addition of fly ash the lime treated soil was ripped out by a motor patrol and repulverized by use of road mixers. The pulverization was continued until the proper gradation of 60 percent passing a No. 4 sieve was obtained, at which time fly ash was added.

Fly ash was delivered to the job site in 25-ton loads by means of transport trucks. Due to the loose soil, the transport trucks were pulled by a motor patrol to insure uniform distribution. Dusting was again considered to be a problem and the canvas "tent" was utilized to reduce this problem.

The mixing of fly ash with the subgrade material in any test section did not begin until all the fly ash was placed. Because of the fast set times of fly ash, water was not added to control dusting; instead a disk plow was used in the treated area to 'pre mix' the fly ash-soil. After initial mixing, all the treated soil was bladed away from the roadway and pneumatic roller was applied to compact the soil below. Next, half of the treated soil was bladed back into place, watered to optimum moisture (around 17%) and compacted by means of a hyster compactor. To seal the bottom half of the subgrade, it was compacted with a pneumatic roller. This process was repeated for the top half of the subgrade. Compaction in two lifts was performed to insure 95% of laboratory density. One test section took approximately 10 hours to place and compact lime-fly ash stabilized soil, but only three hours elapsed after water was first applied to the fly ash until compaction was complete. This procedure was followed to maximize the benefits of the cementitious action. Table 6 summarizes the actual percentages of lime and fly ash placed in the test sections, along with pertinent soil data.

Construction proceeded smoothly and no problems were encountered.

Table 6. Lime-Fly Ash Stabilization Data for Test Site 5 (FM 1604 in Bexar County) RS 1855(8)

Test Section No.	Final Lime/Fly Ash % (by Wt.) Design/actual		Date of Construction	Plasticity Index (PI)	Final % Passing No. 4 Sieve[a]	Moisture Content[a] (%)	Field Density[a] (lb/ft³)	Percent of Laboratory Density[b]
1	3/6	2.9/5.8	Apr. 1980	12	66	12.9	113.3	98.0
2	3/9	2.7/7.6	Apr. 1980	3	84	13.5	112.6	95.0
3	0/12	0.0/9.8	Apr. 1980	8	68	11.8	114.4	95.2
4	2/8	1.9/7.8	Apr. 1980	11	68	11.6	111.0	98.8
5	4/0 (control)	4.0/0.0	Mar. 1980	23	66	16.1	105.7	99.4
6	1½/5	1.5/5.7	Apr. 1980	9	70	12.4	109.2	96.0

[a] Average of three or four measurements

[b] As determined by test method Tex-114-E or other approved methods.

2.2.6 Test Site 8, SH 335, Potter Co. This project, in Amarillo, Tx., involved the construction of six lime-fly ash soil stabilization test sections. Typical sections, the general layout of test sections, and a list of equipment used are found in Appendix A (Figures A-11 and A-12 and Table A-6). The test sections were all approximately 800 feet long and were stabilized with various amounts of lime and fly ash (from plant H). The soil was a medium to low PI clay. The lime-fly ash subgrade test sections were constructed from February 28 through March 9, 1979.

Lime was delivered to the project by truck, normally in 25 ton loads and was transferred from the transports into a tank and mixed with water for application in slurry form. A 30% solution of a lime slurry was used (500 gal of water per ton of lime). Mixing of the slurry was performed by circulating air through the tank and by constant circulation of the water and lime by use of a pump during transfer of the slurry to distribution trucks. After mixing, the slurry was pumped into water trucks for distribution.

Before the lime slurry was applied the area had been compacted and shaped to line and grade. The area was then undercut to a six in. depth by using a motor grader and a D-8 Dozer with cutter bar. The undercut area was then plowed using a 24 in. disk plow. The lime slurry was applied to the undercut and pre-mixed with the subgrade material by means of the disk plow. Mixing of the lime and subgrade material was continued until the mixture was considered uniform. After mixing of the lime slurry and subgrade material, additional water was added and mixed with the lime treated material until optimum moisture was reached (about 20%). When the mixing was complete the area was bladed over and sealed with a pneumatic tire roller. During the curing period the area was sprinkled with water to prevent drying. Six hours were required to treat around 9,000 yd^2.

Fly ash was delivered to the job site by transport trucks with loads normally ranging from 23 to 24 tons. The fly ash was applied directly from the transport truck on the surface to be treated (Figure 13). Due to calm winds no noticeable dusting occurred during application. A uniform rate of distribution was achieved by varying the air pressure (5-10 psi) of the truck along with the speed of truck (1-3 mph) (Figure 14).

The mixing of the fly ash with the subgrade material did not begin until all the fly ash was in place. The initial mixing was performed using the 24 in. disk plow pulled by a 4 wheel drive rubber-tired tractor. The disk plow made at least two complete passes through the area to insure a mixed depth of six in. Next the road mixers were utilized until 60% of the material passed a No. 4 sieve. After gradation was achieved, water was added to attain optimum moisture and a tamping roller compacted the material. Numerous passes were made to insure 95% density was obtained. Finally the water wagons were filled and used as pneumatic rollers to seal the area. Approximately eight hours were required to place and compact 7000 yd^2 of lime-fly ash stabilized soil. Table 7 gives lime/fly ash ratios along with pertinent soil data.

The lime stabilized control section was remixed and compacted following a one or two day cure, and the lime/fly ash sections were remixed one or two days after initial mixing. By doing this, the initial cementitious chemical action between the fly ash and water may

Figure 13. Application of Fly Ash on SH 335 in Amarillo, Texas (Test Site no. 8)

Figure 14. Close up of Fly Ash after application on SH 335 in Amarillo, TX (Test Site No. 8)

Table 7. Lime-Fly Ash Stabilization Data for Test Site 8 (SH 335 in Potter County)

Test Section No.	Final Lime/Fly Ash % (by wt.) Design	Final Lime/Fly Ash % (by wt.) Actual	Date of Construction	Plasticity Index (PI)	Final % Passing No. 4 Sieve[a]	Moisture Content[a] (%)	Field Density[a] (lb/ft^3)	Percent of Laboratory Density[b]
1	2½/0 (control)	2.5/0.0	2/26/79	15	60	23	99	96
2	2/4	2.0/3.9	3/08/79	13	60	20	101	96
3	2/6	1.9/3.9	3/08/79	12	72	19	103	95
4	2/8	2.0/8.0	3/07/79	15	70	22	101	95
5	3/6	3.0/6.3	3/07/79	10	70	24	96	92
6	0/8	0.0/7.7	3/06/79	18	65	19	103	101

[a] Average of three or four measurements

[b] As determined by Test Method Tex-114-E

have been destroyed during the subsequent mixing. Pozzolanic reaction was probably not affected, so only time will tell the effects of this construction procedure.

<u>2.2.7 Test Site 12, FM 2697, Wheeler Co</u>. Originally not intended to be one of the test sites involved in this study, a three mile long project was set up to stabilize a six in. thick sandy soil with 20% fly ash from plant "H" and cover with a two course surface treatment. The soil had a very low PI (around three), a liquid limit of 18, 10% retained on the No. 40 sieve and only 2% passing the No. 200 sieve. Laboratory results indicated that the 20% fly ash mixture was stronger than a mixture of 2% lime, 8% fly ash. This was due to the low amount of fines in the soil for which some of the fly ash became a filler. To measure the effectiveness of the fly ash as a cementitious type stabilizing agent (similar in this case to portland cement), five test sections were constructed with various percentages of fly ash (Table 8). Figures A-13 and A-14 in Appendix A give the test sections' plan locations and typical section.

The surface to be treated was first pulverized with a road mixer and fly ash was placed in a dry method directly on the ground by use of transport trucks with approximately 25 ton loads. A road mixer was used to initially mix the fly ash with the coarse-grained soil (Figure 15). After initial mixing, water was added by use of water trucks with down bars until optimum moisture was obtained, approximately 12%. After it was determined that the optimum moisture content was reached, additional mixing took place until 60% passed a No. 4 sieve. The characteristic of this material was such that 100% would pass a #4 sieve when mixed. Throughout the mixing sequence additional water was added to prevent the soil from "drying out." Once the gradation was obtained, the vibratory roller began compaction (Figure 16). With this type compaction, proper density (95% of laboratory) was obtained throughout the test site. The area was sealed by rolling

Table 8. Fly Ash Stabilization Data for Test Site 12
(FM 2697 in Wheeler County)

Test Section No.	Final Lime/Fly Ash Percentage (by wt.)	Date of Construction	Plasticity Index (PI)	Final % Passing No. 4 Sieve[a]	Moisture Content[a] (%)	Field Density[a] (lb/ft^3)	Percent of Laboratory Density[b]
1	0/20	10/22-26/79	3	100	7.5	114.9	96.3
2	0/30	10/29/79	3	100	8.9	120.0	100
3	0/40	10/23/79	2	100	9.2	112.8	95.6
4	0/20	10/17-19/79	2	100	9.9	116.3	98.0
5	0/40	10/25/79 11/15-17/79	2	100	9.7	114.7	96.7

[a] Average of three or four measurements

[b] As determined by test method Tex-114-E

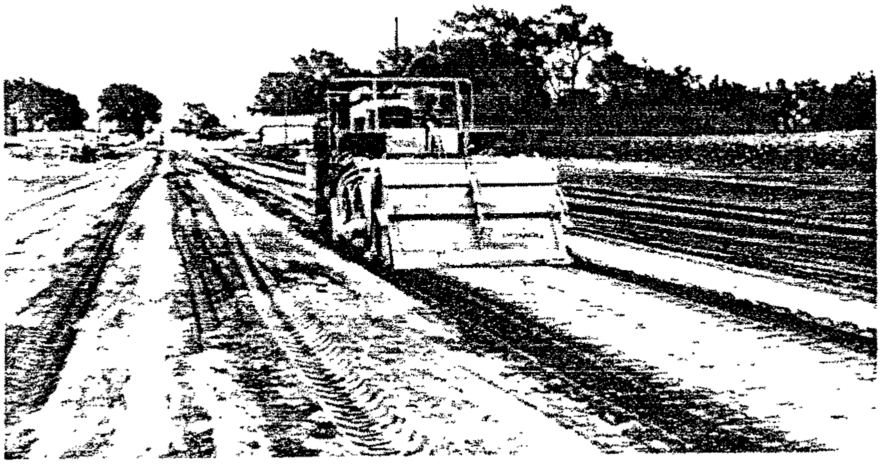


Figure 15. Initial Mixing of Fly Ash on FM 2697 in Wheeler, TX (Test Site No. 12)

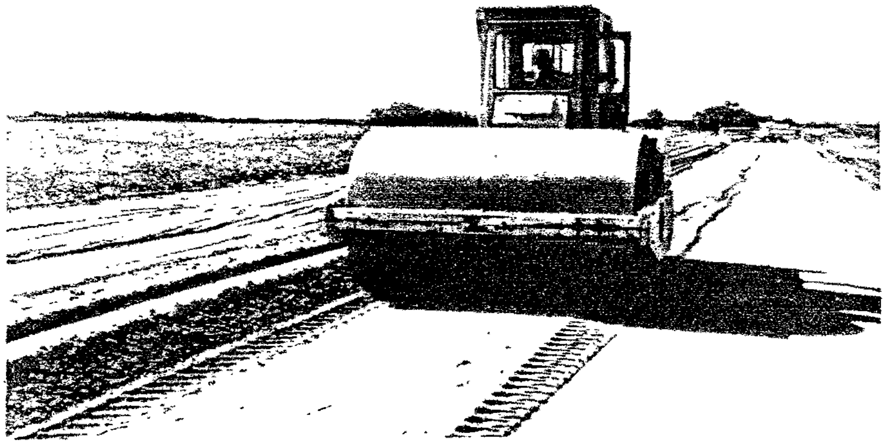


Figure 16. Vibratory Compaction of Fly Ash Stabilized Soil on FM 2697 in Wheeler, TX (Test Site No. 12)

with a 10-ton pneumatic roller. The area was then sealed with an asphalt prime coat (MC-30).

Test section 5 was constructed with 20% fly ash using the above procedure, except that instead of immediately sealing with asphalt, the following procedure was used:

The day after stabilization, one in. of material was bladed from the surface, watered and recompacted. This was done for seven consecutive days to help cure the section. After this curing procedure the area was sealed with a prime coat. Two months later the area was being tight bladed to grade when large, thin, sheets (around 2 ft. diameter) broke from the surface. Upon further examination it was discovered that the top portion of this fly ash stabilization section had become laminated with little or no bond between the layers. The section was restabilized using an additional 20% fly ash and sealed with an asphalt prime course.

After stabilization, but before a riding surface was placed on the surface, a large truck traveled Test Section 3 causing deep rutting. The area rutted was rescarified, and an additional 20% fly ash was added, mixed, brought to optimum moisture and recompacted. Thus Test Section 3 and 5 ended up with 40% fly ash. Interestingly the stabilized sections did not develop any shrinkage cracks normally associated with portland cement stabilization of bases. Approximately 1100 feet of roadway was stabilized a day using this construction sequence.

This type of stabilization resembles cement treatment and thus is quite different from lime-fly ash stabilization of clay-type soils. Moderate to heavy amounts of fly ash were added to a sandy soil with little problem! Reworking after the fly ash set up was shown to be very detrimental (as would be expected). But even when large amounts of fly ash were added, no shrinkage cracks were observed as the sections cured. (In all probability there were some cracks but, if so, they were only hairline and thus completely obscured by the asphalt prime coat.)

Seven months after placement - during the summer of 1980 - a few blow ups (lateral fractures) occurred in Test Section No. 5 (containing 40% fly ash), and test section #2 (containing 30% fly ash). This indicates behavior very similar to cement treated bases and concrete pavements, and can be attributed to the heavy amounts of fly ash creating stabilized material with a relatively high thermal coefficient of expansion. Being retained from expansion the stabilized section was thrown into compression and, due to excentricities in internal loading, blow ups occurred. Lateral fractures of this nature were found in all sections containing over 20% fly ash.

2.2.8 Test Site 13, US 87, Wilson Co. This project used lime-fly ash to stabilize the top six in. of an 18 inch existing river gravel flexible base. The amount of material used was seven lb/yd^3(1 1/2%) of lime, and 28.3 lb/yd^3(6%) of fly ash from plant D. This test site was also not originally intended to be included in the study and thus did not contain a number of test sections. But because this site contained a markedly different type of material (river gravel flexible base) it was decided to monitor construction and learn how lime-fly ash stabilization would perform with such a base material. Figure A-15 in Appendix A gives the typical section for this project. The test site is approximately 1 1/2 miles in length and is located 2 miles southeast of Stockdale. This project was constructed during April 1980. The base had a PI of 7.0. Optimum moisture was 8.2%.

First, the top six in. of the existing base were scarified in the late afternoon and lime was added in the dry form. One to two passes were made with a pulvermixer to insure the mixing of the old base material with the lime. This was done, before the fly ash was added, to help 'cure' the material. The following day the fly ash was added in dry form and mixed using the pulvermixer. After this mixing, water was added to maintain optimum moisture and the material remited and compacted. The material was first compacted with two passes of a vibratory compactor which was followed by four to six passes of sheepsfoot roller. When it appeared the mix was approaching 95% density, the sheepsfoot roller was removed and compaction, using a pneumatic roller, was used to seal and compact the surface. After compaction, traffic was allowed to travel the area previously stabilized. A one in. asphaltic concrete pavement was placed, as a riding surface, approximately two weeks later.

No problems were encountered with this type of stabilization. The lime and fly ash were intimately mixed and the base compacted with ease. An average field density of 127.8 lb/ft^3 was easily achieved.

2.3 Fly Ash-Portland Cement Concrete Pavement Projects

2.3.1 General. Three sites were selected where a portion of the portland cement was replaced with fly ash (see Figure 3). At each site at last four test sections were constructed with the following equal lb. per lb. weight replacements of portland cement with fly ash (0 {control}, 15, 20, and 25 percent). Each project was constructed in accordance with applicable SDHPT specifications for the type of concrete pavement involved. The concrete quality and construction procedures were carefully monitored to identify any problems that might have occurred. As expected, no significant problems were observed as a result of the use of fly ash and, thus, it can be concluded that the use of fly ash should pose no construction problems. Each site is discussed in the following sections.

2.3.2 Test Site 9, IH 27, Hale Co. This test site contains the four test sections (0, 15, 20, and 25% fly ash mixtures) as part of a nine in. thick continuously reinforced concrete pavement on the south bound outside lane and shoulder (a 22 ft wide strip comprising the outer 12 ft lane and a 10 ft wide concrete shoulder) of IH 27 north of Lubbock. In addition on the northbound outside lane and shoulder four replicate test sections were constructed (0, 15, 20, and 25% fly ash mixture). The concrete was placed during June and July 1980. The test site layout and typical section are given in Figures A-16 and A-17, Appendix A. Fly ash from plant "H" was used.

The concrete, constructed in conformance with SDHPT Item 366, was hauled to the site in dump trucks after being produced in a 12 yd^3 capacity central batch plant (Figure 17), set up by the contractor on the project. Average haul time was eight minutes. The concrete was spread by a side-loading concrete spreader (Figure 18), screeded, vibrated and formed to finished dimensions by a traveling form paver (Figure 19), and smoothed by a tube float (Figure 20). The contractor elected to attach a burlap drag to the tube float to impart an initial texture to the pavement surface. Following the tube float was the texturing machine which imparted a transverse tines finish to the pavement, as well as white pigmented curing compound (Figure 21).

No construction problems were encountered and the contractor was able to maintain an average rate of progress of nine ft/min. Quality control was carefully monitored, and beams and cylinders were molded, covered for 24 hours, then transported to lime-water storage for later testing. Concrete data for the four test sections in the southbound lanes are summarized in Table 9A.

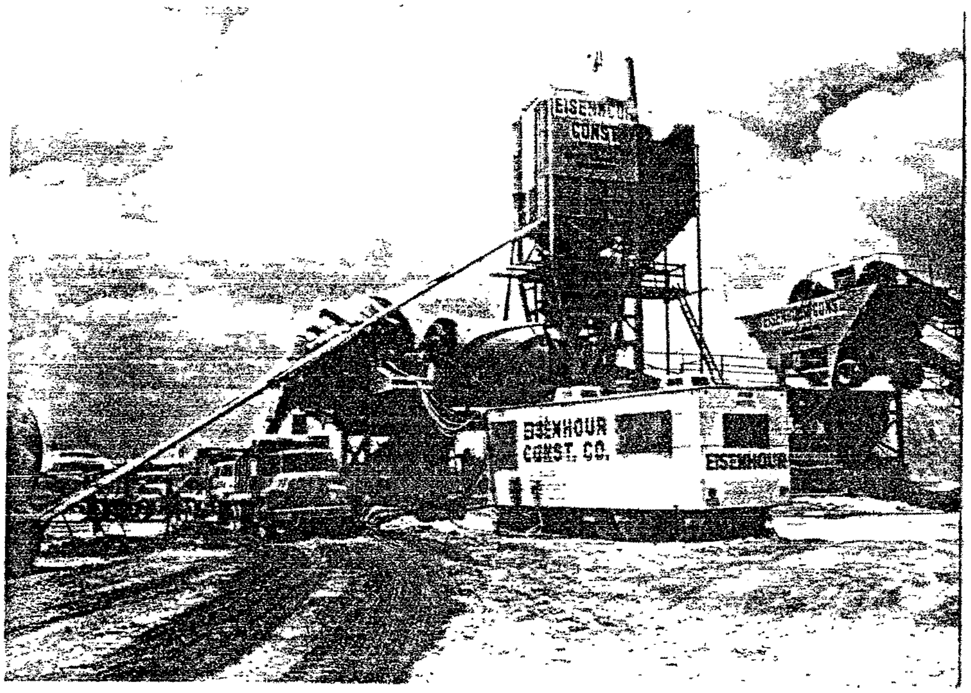


Figure 17. Twelve cu.yd. Concrete Batch Plant on IH 27, Hale Co., (Test Site 9).

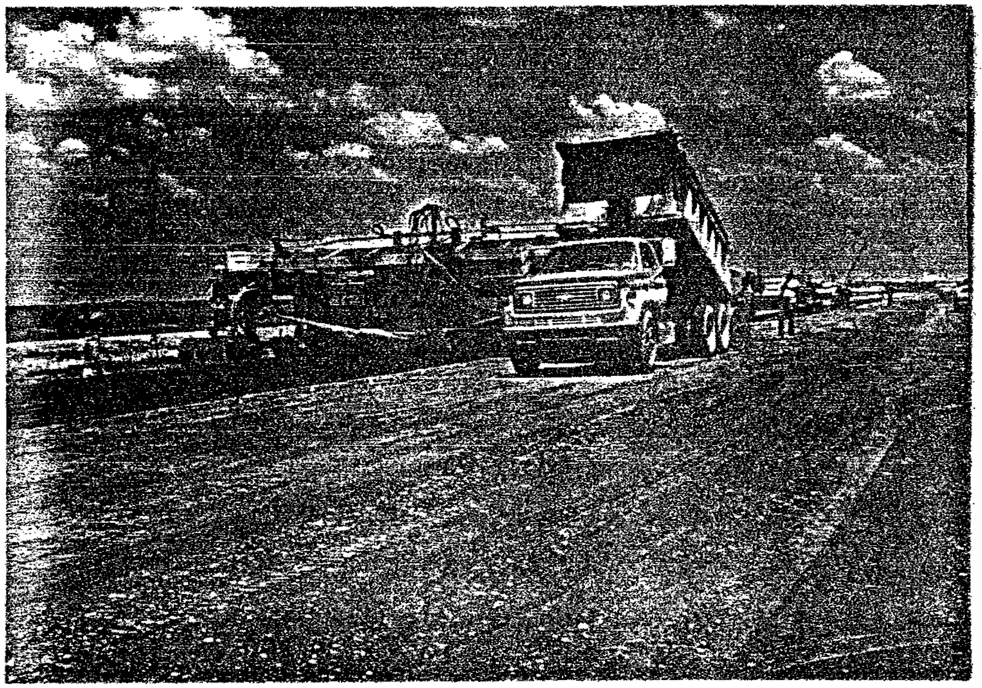


Figure 18. Side Loading Concrete Spreader on IH 27, Hale Co., (Test Site 9).

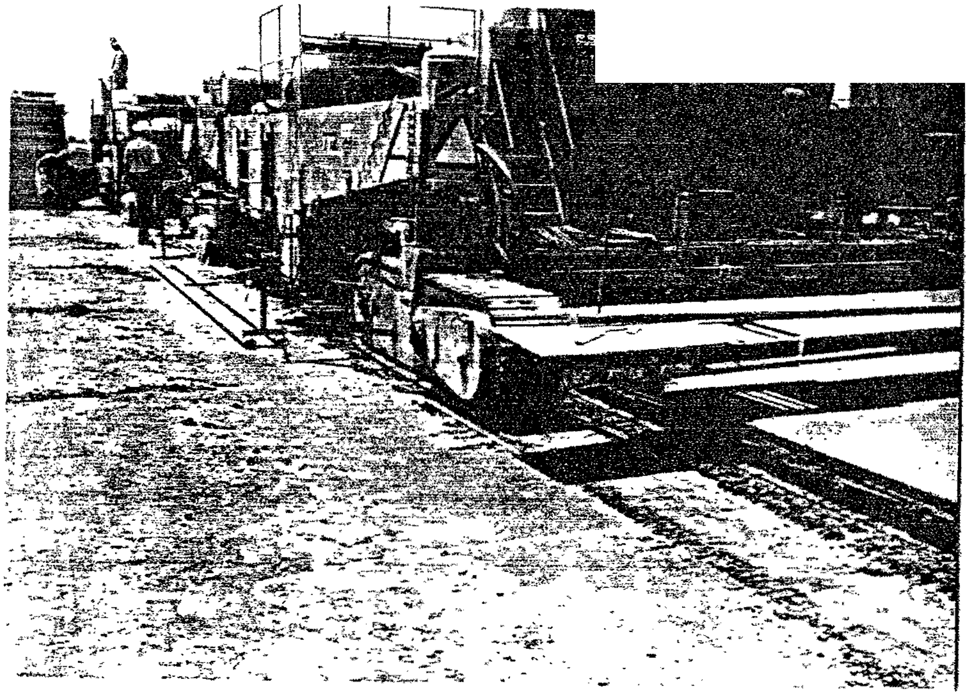


Figure 19. Slip Form Concrete Paving Machine, IH 27, Hale Co., (Test Site 9).

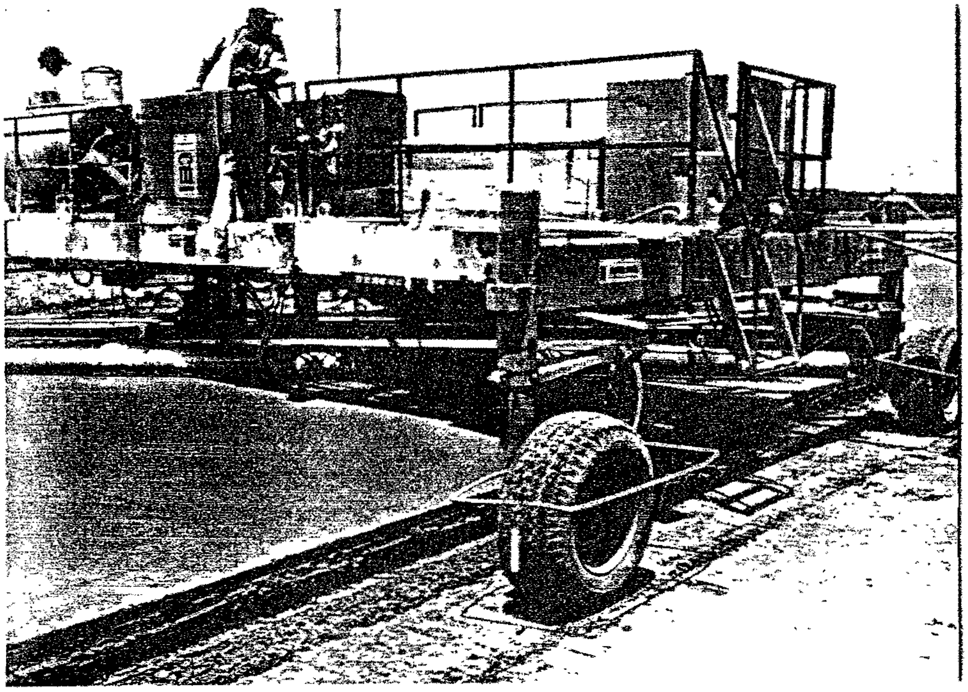


Figure 20. Tube Float Machine on IH 27, Hale Co., (Test Site 9).

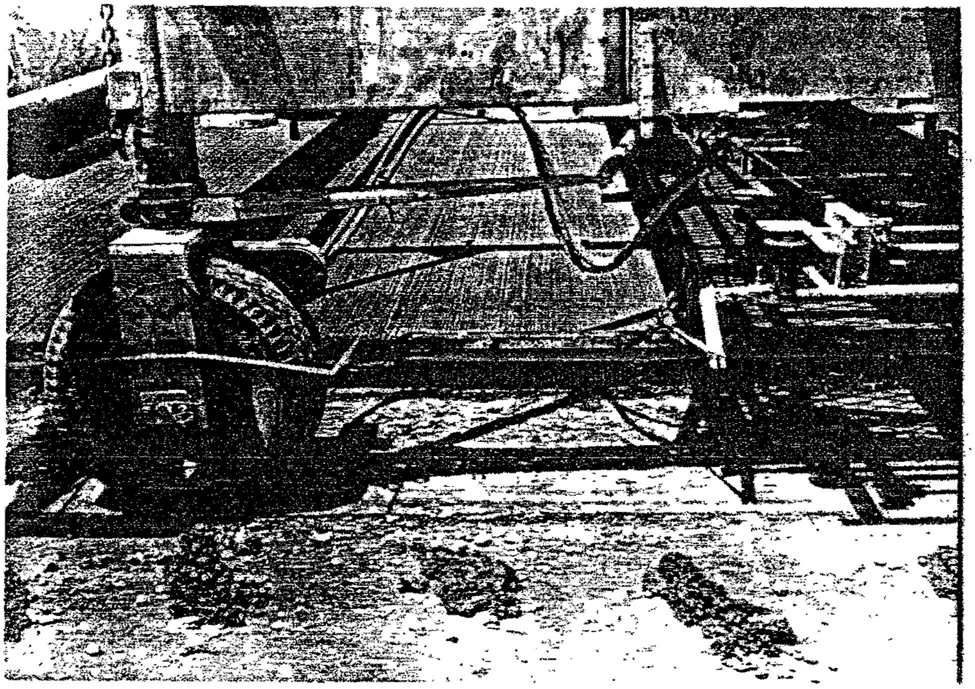


Figure 21. Transverse Tines Finishing Machine on IH 27, Hale Co., (Test Site 9).

Table 9A. Concrete Batch Information on Test Site No. 9 (south bound lanes); IH 27, Hale County

Item		0% Fly Ash (Control)	15% Fly Ash	20% Fly Ash	25% Fly Ash
BATCH CODE		C	P-1	P-2	P-3
Design Quantities per Cubic Yard					
Cement (General Portland)	(lbs)	470	400	376	352
Fly Ash (Plant H)	(lbs)	-	70	94	117
Water	(lbs)	250	240	260	260
Fine Aggregate	(lbs)	1145	1165	1105	1100
Coarse Aggregate	(lbs)	2025	2025	2025	2025
Water Cement Ratio	(gal/sk)	6.0	5.75	6.25	6.25
Cementitious Factor	(sk/yd^3)	5	5	5	5
Average Field Measurements					
Slump	(in.)	1 1/8	1 3/8	1 1/2	1 1/8
Air Content	(%)	3.5	3.2	3.5	4.0
Concrete Temperature	(°F)	79	78	82	82
Compressive Strength[a]	15 day	5090	5100	5750(16d)	5010(16d)
Moist Cured, psi	28 day	4900	5350	6340	5400
(ASTM C 39)	90 day	5330	5980	6910	6200
	180 day	5620	6590	7460	6540

9A.

Table 9. Concrete Batch Information on Test Site 9 (south bound lanes), IH 27, Hale County (Continued)

Item		Control	15% Fly Ash	20% Fly Ash	25% Fly Ash
BATCH CODE		C	P-1	P-2	P-3
Flexural Strength[a] Moist Cured, psi (ASTM C-78)	7 day	690	710	750	670
	28 day	790	800	840	850
	90 day	---	770	920	970
Compressive Strength 4 inch cores-moist cured after 90 days in place	180 day	6010	6270	6480	6230
Texture Readings, in.	as const.	0.079	0.066	0.064	0.069
Skid Number[b] 180 days	20 mph		Data are incomplete on 20 mph.		
	40 mph	57	55	52	59
	50 mph	58	55	54	56

[a] Average of two values

[b] Average of ten readings

Concrete data for the replicate sections in the north bound lanes are given in Table 9B.

The concrete strengths indicate that excellent strengths were achieved for all concrete mixes, in every case exceeding the control strengths (both compressive and flexural). From a strength viewpoint fly ash-in percentage replacements up to at least 25 - can effectively replace portland cement in concrete pavement. Excellent textures were also achieved, as evidenced by the high texture numbers and skid numbers.

Table 9B. Concrete Batch Information on Test Site No. 9 (North Bound Lanes), IH 27, Hale County

Item		0% Fly Ash (Control)	15% Fly Ash	20% Fly Ash	25% Fly Ash
BATCH CODE		CR	P-1R	P-2R	P-3R
Design Quantities per Cubic Yard					
Cement (General Portland)	(lbs)	470	400	376	353
Fly Ash (Plant H)	(lbs)	0	70	94	117
Water	(lbs)	250	240	260	260
Fine Aggregate	(lbs)	1145	1165	1105	1100
Coarse Aggregate	(lbs)	2025	2025	2025	2025
Water Cement Ratio	(gal/sk)	6.0	5.75	6.25	6.25
Cementitious Factor	(sk/yd^3)	5	5	5	5
Average Field Measurements					
Slump	(in.)	1½	1½	1½	1½
Air Content	(%)	5.0	5.0	5.3	4.0
Concrete Temperature	(°F)				
Compressive Strength[a]					
Moist Cured, psi	28 day	-	5560	5230	5230
(ASTM C 39)	90 day	-	5500	6130	6270
	180 day	-			
	365 day	-	7300	5800	6460

Table 9B. Concrete Batch Information on Test Site 9 (North Bound Lanes), IH 27, Hale County (Continued)

Item		Control	15% Fly Ash	20% Fly Ash	25% Fly Ash
BATCH CODE		CR	P-1R	P-2R	P-3R
Flexural Strength[a] Moist Cured, psi (ASTM C-78)	7 day	-	620	710	700
	28 day	-	830	840	740
	90 day	-	900	910	870
Compressive Strength	180 day	-	6330	6400	6180
4 inch cores-moist cured after 90 days in place	300 day	5450	-	-	-
	365 day	-	6840	6920	6210
Texture Readings, as const. in.		0.063	0.039	0.056	0.058
Skid Number[b] ∿ 180 days	40 mph	59	55	53	61

[a] Average of two values

[b] Average of ten readings

2.3.3 Test Site 10, Scott Street in Houston, Texas. A test site with four test sections of various percentages of fly ash-portland cement concrete was placed two miles south of Loop 610 on Scott Street in Houston, Texas. A layout of the test site along with a typical section of Scott Street are given in Appendix A of this report (Figures A-18 and A-19). The portland cement concrete was centrally batched at a ready mixed concrete company's plant and placed into eight yd^3 ready mixed trucks (Figure 22). Fly ash from Plant "P" was added after batching by use of a separate silo (Figure 23). An average haul time of approximately 40 minutes was experienced from the batch plant to the job site due to the distance between the two locations and traffic conditions. Quality was carefully monitored with several slump tests taken from trucks in a random fashion. Beams and cylinders were cast from concrete from each test section, covered and left on the site for 24 hours then transported to water storage for later strength determination.

Steel forms were used. Once the concrete was delivered to the job site, it was placed either directly by chute or through a side loading spreader. This was followed by a form-type paving machine which vibrated and consolidated the pavement. The surface was then floated by hand and texture was achieved by use of a burlap drag. Following this a white pigmented curing compound was sprayed on the surface. Figure 24 shows the equipment "spread" used by the contractor.

The project experienced several difficulties, including the problem of controlling batch to batch concrete consistency, and interruptions in delivery of concrete from the batch plant. Numerous delays occurred and trouble was experienced in controlling slump (it varied from one to five in.). Two trucks were rejected for failure to receive fly ash

Figure 22. Parker Bros. Batch Plant in Houston, Texas used on Scott Street in Houston, TX (Test Site No. 10)

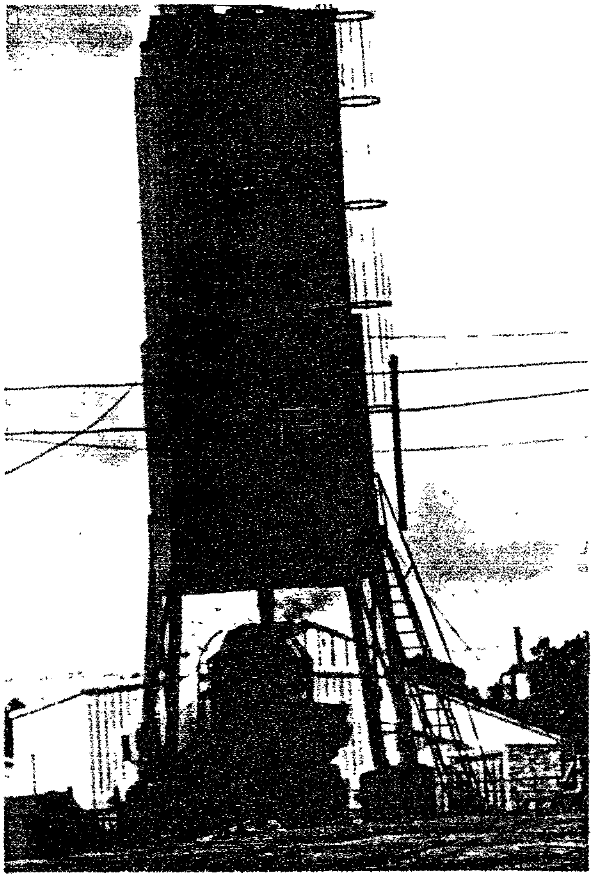


Figure 23. Fly Ash Silo Used on Scott Street in Houston, Texas (Test Site No. 10)

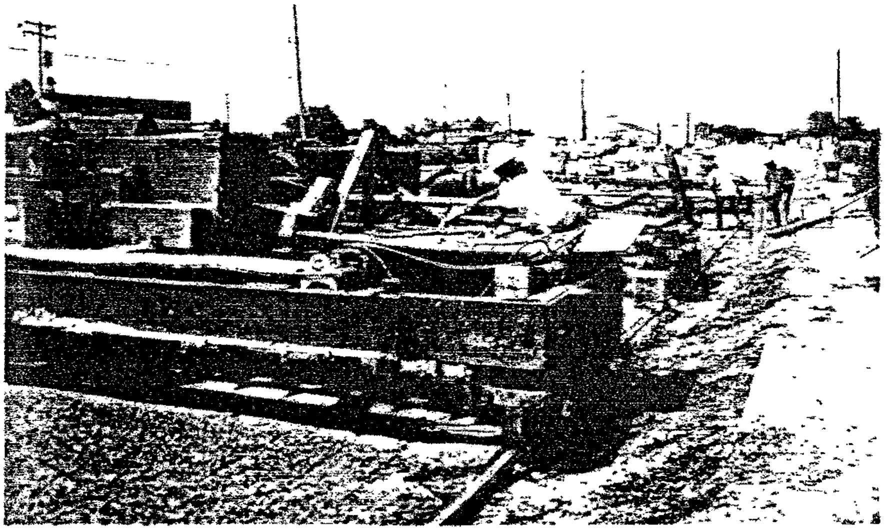


Figure 24. "Equipment Spread" used in Construction of Scott Street in Houston, Texas (Test site No. 10)

from the separate silo at the plant, and a few trucks were rejected for too high a slump. Also intermittent rains occurred, forcing project shut down and affecting the surface finish.

Information on batch design, strength, texture, and skid readings are summarized in Table 10. Compressive strengths look very good, although some data scatter is apparent. From the data, the 15% fly ash mixture exhibited somewhat lower compressive and flexural strengths (with respect to control) and also erratic results, while both 20% and 25% mixtures exhibited higher strengths than control at all ages. Thus the 15% values are questionable and it would appear that the use of fly ash, in replacement percentages of up to 25%, would not be detrimental to strength. To the contrary, long term strength development seems to be enhanced by the use of the fly ash. Although difficulties were experienced, they were not due to the use of fly ash - other than the difficulty of control when another admixture is introduced. Adequate texture depths were achieved, as well as suitable initial skid numbers.

Table 10. Concrete Data on Test Site 10, Scott Street, Houston, Texas

Item		Control	15% Fly Ash	20% Fly Ash	25% Fly Ash
BATCH CODE		C	P-1	P-2	P-3
Design Quantities Per Cubic Yard					
Cement (Trinity)	(lbs)	470	400	376	352
Fly Ash (Plant P)	(lbs)	-	70	94	118
Water	(lbs)	225	225	225	217
Fine Aggregate	(lbs)	1385	1253	1251	1274
Coarse Aggregate	(lbs)	2087	2087	2087	2087
Retarder (MASTER Builders 300 R)	(oz)	25	25	25	25
Water Cement Ratio		0.48	0.48	0.48	0.48
Cementitious Factor	(sk/yd^3)	5	5	5	5
Average Field Measurements					
Slump[a]	(in.)	2 1/2	2 1/2	1 3/4	3
Air Content	(Percentage)	2	2.5	1.5	1.5
Concrete Temperature	(°F)	84	81	86	85
Compressive Strength[b]	7 day	3580	3660	3840	3900
Moist Cured, psi	28 day	4560	4100	5590	4690
(ASTM C39)	90 day	5000	3090	6410	5650
	180 day	-	5730	7380	6110

Table 10. Concrete Data on Test Site 10, Scott Street, Houston, Texas (Continued)

Item		Control	15% Fly Ash	20% Fly Ash	25% Fly Ash
BATCH CODE		C	P-1	P-2	P-3
Flexural Strength[b] Moist Cured, psi (ASTM C-78)	7 day	560	460	620	550
	14 day	630	-	680	-
	28 day	650	580	780	670
	90 day	690	520	800	680
	180 day	-	760	880	-
Compressive Strength 4 inch cores-moist cured after 90 days in place	180 day	7360	6990	7480	6050
Texture Readings[b]	as const.	0.047	0.070	0.065	0.075
	180 day	0.026	0.041	0.042	0.045
Skid Number[c] as constucted	20 mph	47	47	54	57
	40 mph	38	41	40	42
	50 mph	36	37	36	37

a. Values shown are from samples taken for cylinders and beams. Actual slumps varied in each Test section from 1½ in. to more than five in.

b. Average of ten values

c. Average of two values

2.3.4 Test Site 11, Loop 12, Dallas Co. This test site consisted of an eight in. thick, continuously reinforced, concrete pavement on Loop 12 in Dallas, Texas. The four test sections ({control} 15, 20 and 25 weight percent fly ash replacement of portland cement) were constructed during the period from November 1979 through July 1980 using fly ash from plant "B". Test Site layout, typical section, and material data are given in Appendix A, (Figures A-20 and A-21). The concrete, conforming to the requirements of SDHPT Item 366, was produced for the contractor by a commercial ready mixed concrete plant in eight yd^3 quantities (Figure 25), and hauled to the site in dump trucks. Average haul time to the project was 15 minutes. On site, the concrete was placed on the prepared subbase through a side loading concrete spreader. This was followed by a slip form concrete paving machine, tube float, and texturing machine - all similar to those used on Test Site 9 (see section 2.3.2). As soon as the pavement was sufficiently firm (usually within 20 minutes) the surface was textured with longitudinal tines (1/4 in. steel wires with 1/4 in. clear spacing) (Figure 26). After the surface "sheen" had disappeared the surface was sprayed with a white pigmented curing compound (Figure 27). No significant problems were encountered, although delays and concrete of variable slump and air content were experienced due to the fact that the ready mixed concrete supplier kept preparing different concrete batches for other customers during the time he was supposed to be producing concrete for this project. The concrete was carefully inspected, with frequent slump and air content measurements made. A number of beams and cylinders were molded, covered for 24 hours and then transported to lime water storage for later strength determination.

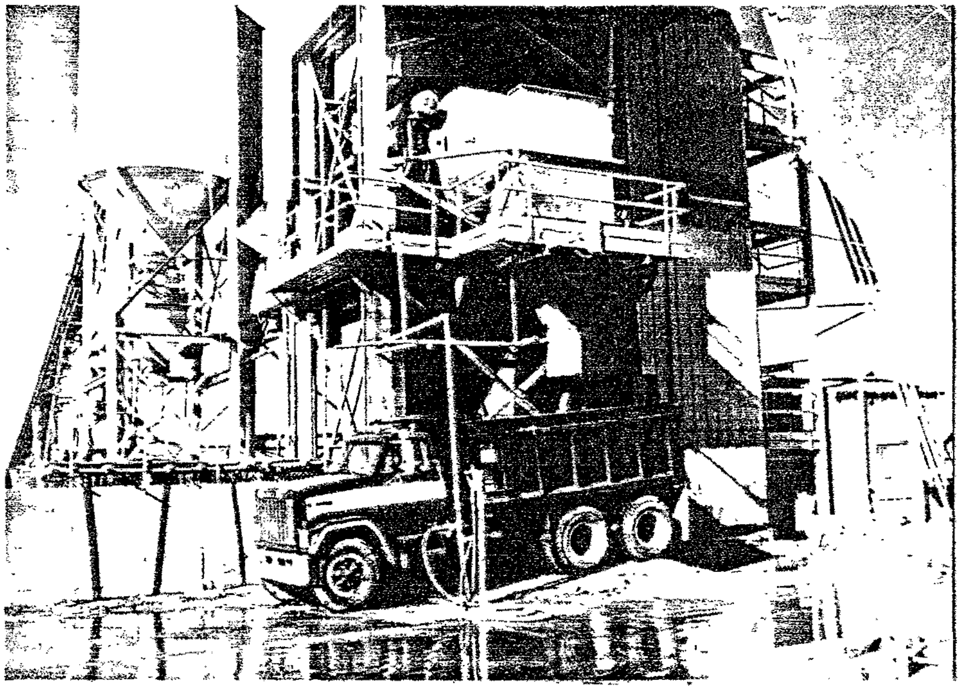


Figure 25. Commercial Ready Mixed Concrete Batch Plant used on Loop 12, Dallas Co. (Test Site 11).

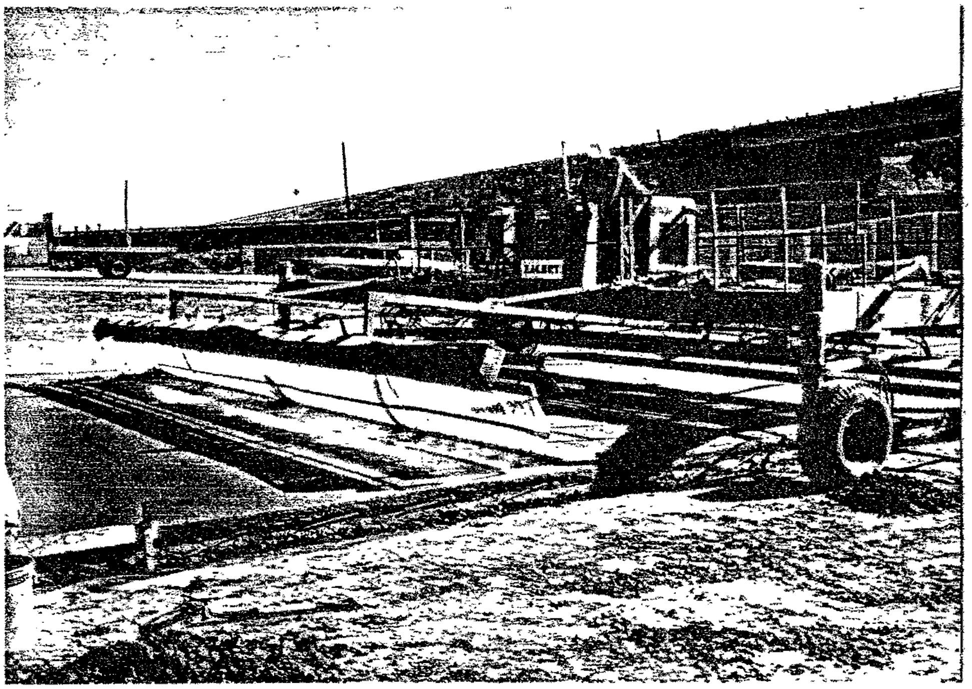


Figure 26. Longitudinal Tines Texturing Machine on Loop 12, Dallas Co. (Test Site 11).

Figure 27. Finished Concrete Pavement showing curing compound on Loop 12, Dallas Co. (Test Site 11).

The concrete mix proportions, mix properties, and strength data are summarized in Table 11. The results show that while the 15 and 25 percent replacement fly ash achieved acceptable strengths in 7 days, the 20 percent fly ash mix exhibited significantly lower compressive and flexural strengths. Obviously, this is an anomalous result; probably due to either the inherent occasional variable nature of concrete batches, or that particular set of test specimens being damaged in shipment to the lab. Interestingly, the strengths of the anomalous 20% fly ash mixture increased significantly as the concrete aged. Note that at seven days its relative flexural strength was only 71% of control, but at 28 days its relative flexural strength had risen to 83% of control. The compressive strength results bear this out because while the 28 relative strength of the 20% fly ash mixture was quite low-only 48% of 28 control - by 90 days of age its relative strength had climbed to 71% of control and after 365 days it's strength exceeded the control strength. The other fly ash mixtures show similar long term strength gains attesting to the beneficial pozzolanic effects of the fly ash. At 365 days of age the 25% mixture achieved remarkable high compressive strengths (8670 psi).

Table 11. Summary of Concrete Data on Site 11, Loop 12, Dallas, Texas.

Item		Control	15% Fly Ash	20% Fly Ash	25% Fly Ash
BATCH CODE		C	P-1	P-2	P-3
Date Placed		2/20/80	11/29/79	12/7/79	2/19/80
Design Quantities Per Cubic Yard					
Cement (Trinity)	(lbs)	470	399	376	352
Fly Ash (Plant B)	(lbs)	-	71	94	118
Water	(lbs)	208	208	208	208
Fine Aggregate	(lbs)	1271	1258	1254	1250
Coarse Aggregate	(lbs)	2023	2023	2023	2023
Retarder (MASTER BUILDERS 300R)	(oz)	19	19	19	19
Air Entraining Agent (MASTER BUILDERS, MB-VR)	(oz)	10	10	10	10
Water Cement Plus F.A. Ratio (wt)	-	0.44	0.44	0.44	0.44
Cementitious Factor	(sk/yd^3)	5	5	5	5
Average Field Measurements					
Slump	(in.)	2	1 1/2	1 1/2	1 3/4
Air Content	(Percentage)	3.4	3.9	4.4	3.7
Concrete Temperature	(°F)	61	63	65	56
Compressive Strength[a]	7 day	-	4550	2610	-
Moist Cured, psi	28 day	6750	5930	3260	7180
(ASTM C39)	90 day	7320	6730	5180	8700
	180 day	7280	8490	6070	8080
	365 day	7450	8360	7660	8670

Table 11. Summary of Concrete Data on Site No. 11, Loop 12, Dallas, Texas (Continued).

Item		Control	15% Fly Ash	20% Fly Ash	25% Fly Ash
BATCH CODE		C	P-1	P-2	P-3
Flexural Strength[a]	7 day	720	610	500	670
Moist Cured, psi	28 day	820	840	750	840
(ASTM C-78)	90 day	950	930	790	950
	180 day				
Compressive Strength 4 inch cores-moist cured after 90 days in place	180 day				
Texture Readings[b]	as const.	0.050	0.034	0.034	0.046
	90 days	0.036	0.030	0.029	0.032
Skid Number[b]	20 mph	65	71	72	69
As constructed	40 mph	60	61	62	59
	50 mph	50	50	51	47

a. Average of two or three values

b. Average of ten values

2.4 Fly Ash-Portland Cement Concrete Box Culverts

2.4.1 General. To assess the construction and performance characteristics of fly ash-portland cement concrete in a structural application, box culverts were chosen. One test site was selected and the culverts constructed with various percentages of fly ash replacements on the basis of 1.25 lb of fly ash for every 1.0 lb of portland cement replaced. Concrete was designed to meet the requirements of SDHPT Item 421, modified to allow the substitution of fly ash. Minimum required compressive strength at 28 days was 3000 psi, and minimum required flexural strength at 7 days was 500 psi. The following section summarizes the construction of these culverts.

2.4.2 Test Site 6, Concrete Box Culverts on FM 1604, Bexar Co. Fly ash structural concrete box culverts were placed on FM 1604 near San Antonio, Texas. Box culverts with fly ash replacements of 15, 20, and 25 percent by volume of cement were constructed. Typical half section of the box culverts are given in Figure A-22 (Appendix A).

Fly ash from Power Plant 'D' and Monterrey Type I portland cement were used. The concrete was produced by a commercial ready mixed concrete supplier in San Antonio. The fly ash structural concrete was transported in eight yd^3 ready mixed trucks (average haul time was one hour), and then transferred into a concrete bucket from which the concrete was placed into the box culvert forms. Hand held vibrators were used to consolidate the concrete around the reinforcing steel. Beams and cylinders were molded, covered for 24 hours and transported to lime-water storage for later testing. A summary of culvert locations and concrete data are given in Table 12.

Table 12. Summary of Concrete Data on Site No. 6, FM 1604, San Antonio, Texas.

Item		Control	15% Fly Ash	20% Fly Ash	25% Fly Ash
BATCH CODE		C	P-1	P-2	P-3
Culvert Location		704+50	652+65	678+70	728+80
Date Constructed		7/3/79	9/5/79	6/26/79	6/12/79
Design Quantities Per Cubic Yard					
Cement (Monterrey)	(lbs)	470	404	376	357
Fly Ash (Plant D)	(lbs)	0	94	122	150
Water	(lbs)	292	292	292	292
Fine Aggregate	(lbs)	974	974	974	1172
Coarse Aggregate	(lbs)	2031	2031	2031	2031
Air Entrainment	(oz)	8	8	7	--
W/(C+FA)	--	0.59	0.59	0.59	0.59
Cementitious Factor	(sk/yd^3)	5.3	5.3	5.3	5.4
Average Field Measurements					
Slump	(in.)	4 1/4	4	4 1/4	3
Air Content	(percentage)	3 1/2	7	4	2
Concrete Temperature	(°F)	72	90	89	78
Compressive Strength[a]	7 day	3810	3680	4840	5150
Moist Cured, psi	14 day	3950	4140	5050	5860
(ASTM C39)	28 day	4480	5000	5750	6840
	90 day	4740	5930	6430	7860
	180 day	4950	6250	6980	8200
	365 day	5150	6480	7430	8520

Table 12. Summary of Concrete Data on Test Site No. 6, FM 1604, San Antonio, Texas (Continued).

Item		Control	15% Fly Ash	20% Fly Ash	25% Fly Ash
BATCH CODE					
Flexural Strength[a] Moist Cured, psi (ASTM C-78)	7 day	630	720	650	660
	14 day	660	740	700	780
	28 day	680	740	710	770
	90 day	820	960	850	880
	180 day	850	960	880	990
Compressive Strength	180 day	4410	5560	4820	7760
4 in. Cores moist cured after 90 days in place	365 day	4500	5990	5740	7700

---

[a] Average of two values

During construction the only problem observed was that one P-3 (the 25% replacement) batch was rather sticky and somewhat difficult to finish. Although no air entraining agent was used, 2% entrapped air was found in this batch. Due to the difficulty in finishing, air entraining agent was added in the next batch to be placed to increase workability. As a result an average air content of 5 percent was measured and there were no further problems with workability. No other difficulties were experienced. All mixes easily exceeded the minimum strength requirements and results after 180 days indicate all the concrete mixes were continuing to gain strength. Of special interest is the fact that the 25% replacement batch (Batch P-3) reached the highest 365 day compressive strength (8520 psi), which was 165% of the control strength at 180 days. Cores taken from the structures verified the strength gains exhibited by the fly ash mixes.

3. Conclusions and Recommendations

3.1 Conclusions

Based on the results of the investigation reported herein, the following conclusions are drawn:

1. Lime-fly ash stabilization of clay-type soils can be effectively constructed in the field with a minimum of problems if the following are followed:

a. Initially break down the soil with lime and allow it to cure for at least two days.

b. Add dry fly ash, then mix, water, and compact the soil within a maximum of six hours (to achieve maximum cementitious reaction between the fly ash and the water).

c. Discharge the fly ash from transport truck under very low pressure to minimize dusting.

d. Do not rework a previously stabilized lime-fly ash section.

2. Initial results indicate that fly ash, when used as a partial replacement for lime in stabilizing clay-type soils, will be an effective stabilizing agent.

3. Additional evaluation of the test sites over time will be needed to determine the optimum amounts of lime and fly ash for stabilization.

4. Fly ash stabilization of granular materials can be effectively constructed in the field if the fly ash is handled in a manner analogous with the construction of cement-treated-bases.

5. Construction of fly ash-portland cement concrete pavements pose no special problems and can be effectively prosecuted in the field.

6. Replacing up to 25 percent of the portland cement with fly ash on a 1:1 basis results in no loss of strength. To the contrary, strengths are generally enhanced at all ages.

7. Replacing up to 25 percent of the portland cement with fly ash on a 1.25:1 basis results in significantly higher strengths at all ages. The only problem was a slightly "sticky" batch which was corrected by the addition of air entrainment.

3.2 Recommendations

1. All test sites should be monitored at periodic intervals to ascertain the performance of the various designs involved (already programmed for prosecution).

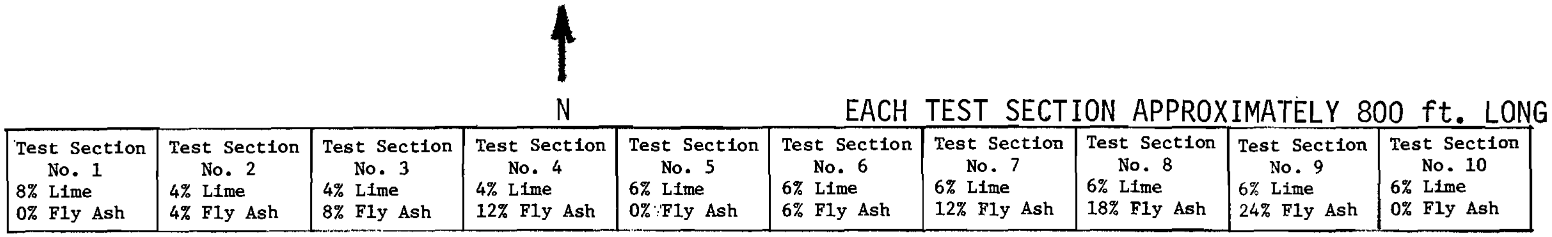
2. Fly ash should be allowed as a partial replacement for both lime and portland cement in highway construction.

3. Construction of highways using fly ash should follow the prescribed guidelines as enumerated in Appendix D.

REFERENCES

1. Meyers, J. F. et. al., "Fly Ash as a Construction Material for Highways," FHWA-1P-76-16, Federal Highway Administration, June 1976.
2. "Lime-Fly Ash - Stabilized Bases and Subbases," NCHRP Report 37, Transportation Research Board, 1976.
3. McKerall, W. C., Ledbetter, W. B., and Teague, D. J., "Analysis of Fly Ashes produced in Texas," Research Report 240-1, Texas Transportation Institute, Texas A&M University, in preparation.
4. Long, R. E., "Soil-Lime Fly Ash Stabilization Research," SDHPT Report 3-05-76-074, Texas State Department of Highways and Public Transportation, June 1978.
5. American Society of Testing and Materials, ASTM Designation C-593, 1977 Annual Book of ASTM Standards, Part 13, pp. 363-367.
6. Terrel, R. L., et. al., "A Guide Users Manual for Soil Stabilization," Federal Highway Administration Contract No. DOT-FH-11-9406, April 1979.
7. Abdun-Nur, E. A., "Fly Ash in Concrete," Highway Research Board Bulletin 284, Transportation Research Board 1961.
8. Woolgar, G. & Oates, D. B., "Fly Ash and the Ready-Mixed Concrete Producer," Concrete International, Vol. 1 No. 11, November 1979.
9. Sutton, Charles A., "Use of Fly Ash in Concrete Pavement Constructed in Nebraska," Highway Research Record, No. 74, Transportation Research Board, 1965.
10. Asrow, S. P., "Fly Ash Usage in Large Commercial Office Building," A paper presented at the Fourth International Ash Utilization Symposium Energy Research Development Administration Publication, SP-76/4, 1976.
11. Stingle, W. M., & Payton, R. L., "Use of Fly Ash as Admixture in an Experimental Pavement in Kansas," Highway Research Record No. 73, Transportation Research Board, 1965.
12. "Use of Fly Ash in Portland Cement Concrete and Stabilized Base Construction," FHWA Notice N 5080.4, Federal Highway Administration, January 17, 1974.
13. American Society of Testing and Materials, ASTM Designation C-618, 1977 Annual Book of ASTM Standards, Part 14, pp. 355-358.

Appendix A. Test Section Layouts and Equipment Spreads.



Test Section No. 1	Test Section No. 2	Test Section No. 3	Test Section No. 4	Test Section No. 5	Test Section No. 6	Test Section No. 7	Test Section No. 8	Test Section No. 9	Test Section No. 10
8% Lime	4% Lime	4% Lime	4% Lime	6% Lime	6% Lime	6% Lime	6% Lime	6% Lime	6% Lime
0% Fly Ash	4% Fly Ash	8% Fly Ash	12% Fly Ash	0% Fly Ash	6% Fly Ash	12% Fly Ash	18% Fly Ash	24% Fly Ash	0% Fly Ash

Figure A-1. Layout Planview of Test Sections on FM 3378 in Bowie County, Texas (Site No. 1)

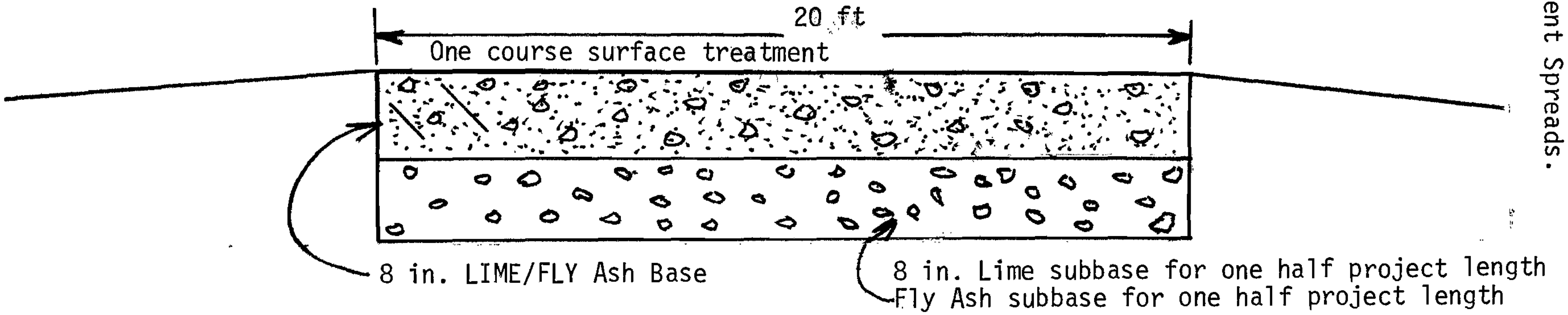


Figure A-2. Typical Section of FM 3378 in Bowie County, Texas (Site No. 1)

N → Each Test Section approximately 1000 ft long

TEST SECTION No. 1	TEST SECTION No. 2	TEST SECTION No. 3	TEST SECTION No. 4	TEST SECTION No. 5	TEST SECTION No. 6	TEST SECTION No. 7	TEST SECTION No. 8	TEST SECTION No. 9	TEST SECTION No. 10
4% LIME	2% LIME	2% LIME	4% LIME	4% LIME	0% LIME	2% LIME	2% LIME	0% LIME	4% LIME
0% FA	4% FA	8% FA	8% FA	4% FA	22% FA	24% FA	16% FA	15% FA	16% FA

Figure A-3. Layout Plan View of Test Sections on US 59 in Panola County, Texas (Test Site No. 2).

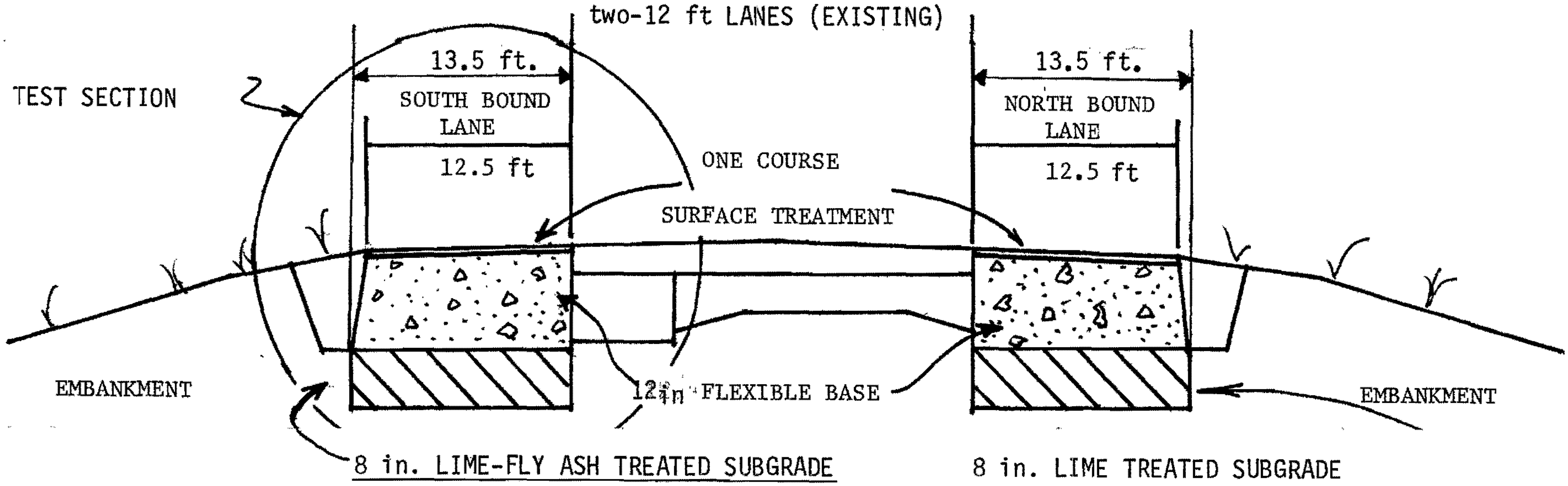


Figure A-4. Typical Section of US 59 in Panola County, Texas (Test Site No. 2).

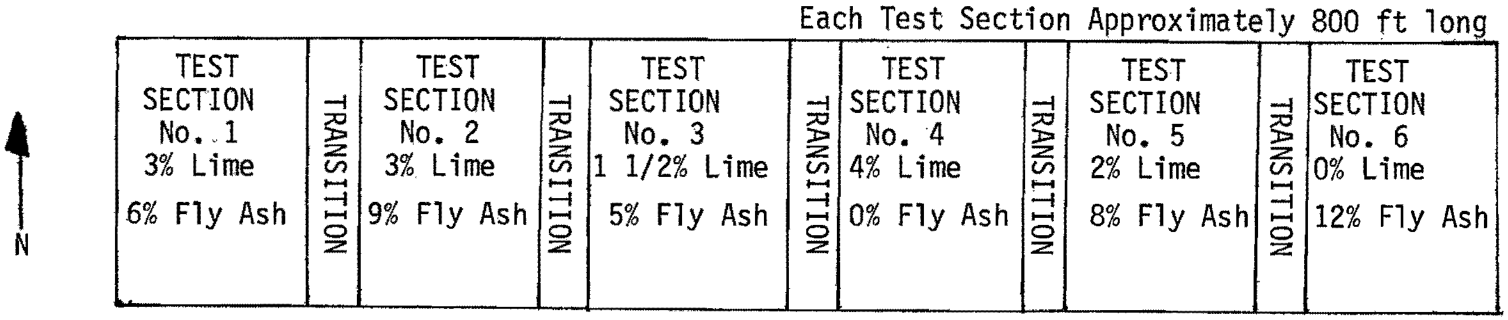


Figure A-5. Layout Plan View of Test Sections on FM 1604 in Bexar County, Texas (Test Site No. 3)

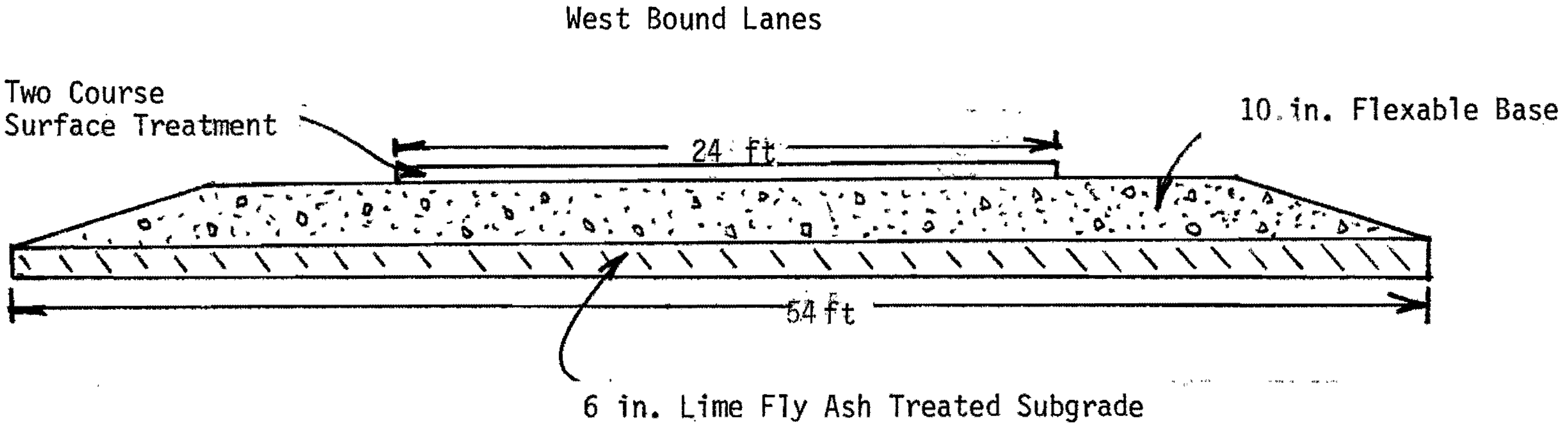


Figure A-6. Typical Section of West Bound Lane on FM 1604 in Bexar County, Texas (Test Site No. 3)

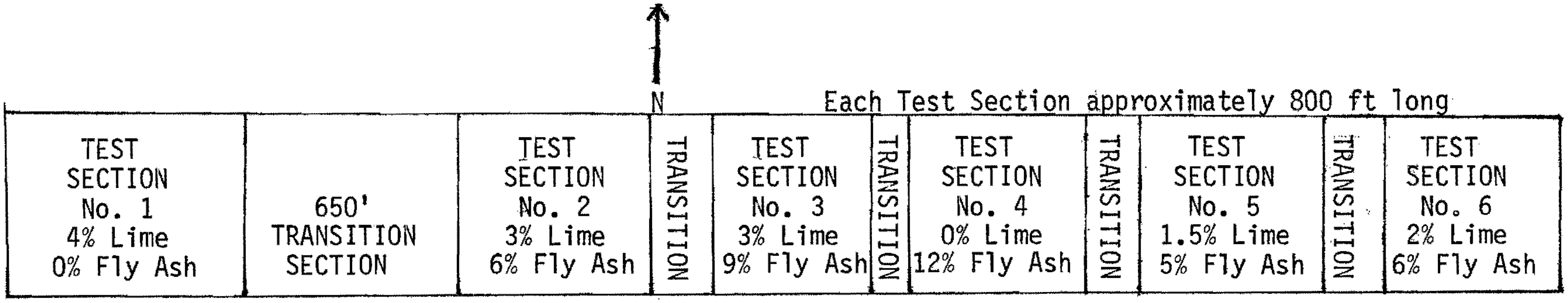


Figure A-7. Layout Plan View of Test Sections on FM 1604 in Bexar County, Texas (Site No. 4)

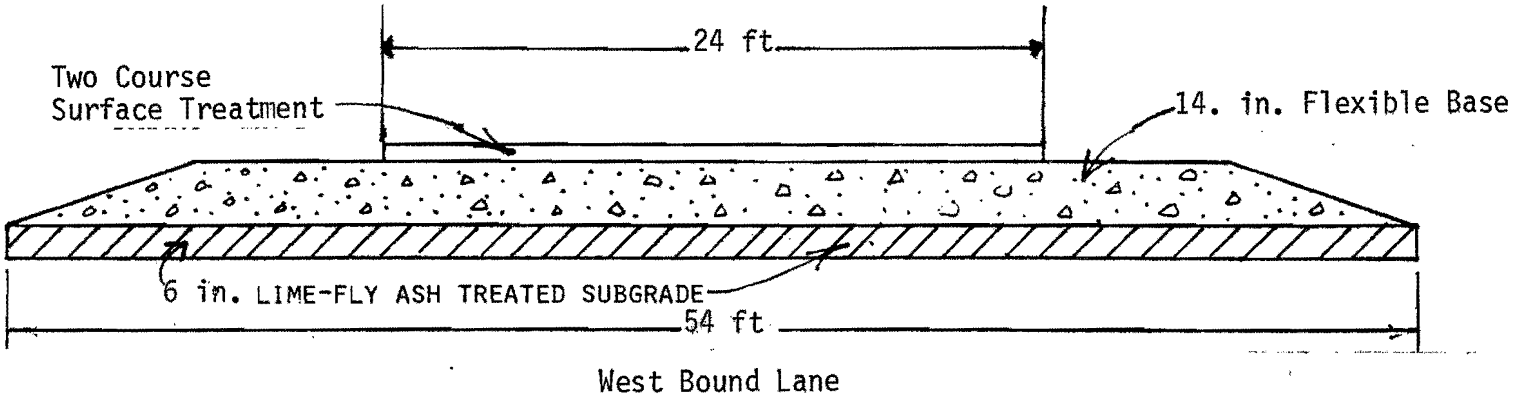


Figure A-8. Typical Section of West Bound Lanes on FM 1604 in Bexar County, Texas (Site No. 4)

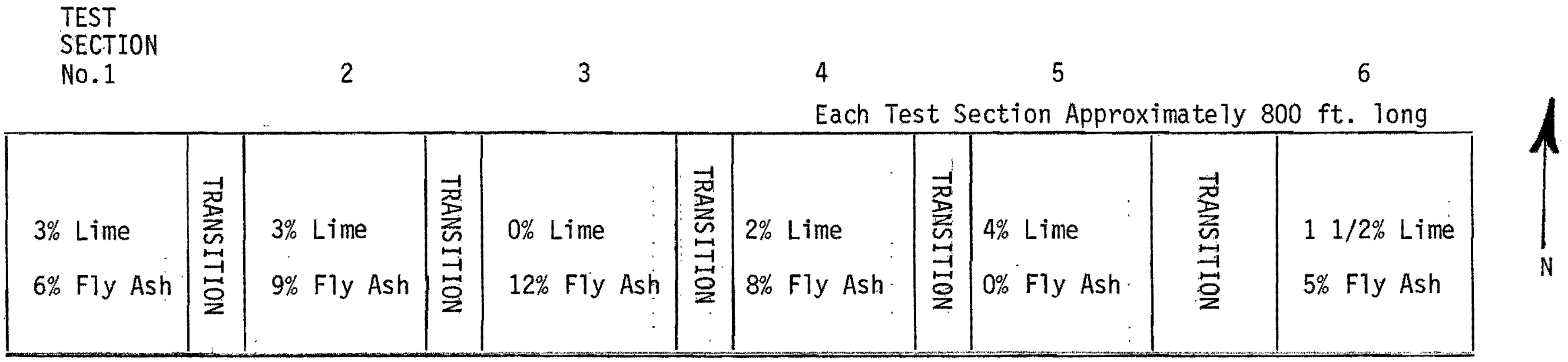


Figure A-9. Layout Planview of Test Sections on FM 1604 in Bexar, County, Texas (Site No. 5)

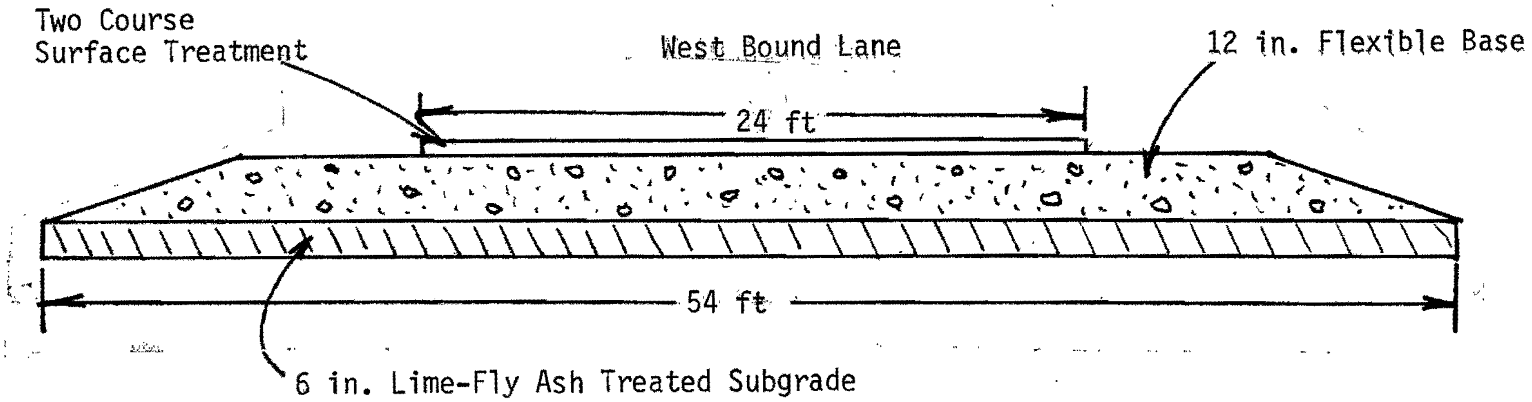


Figure A-10. Typical Section of West Bound Lane on FM 160 in Bexar County, TX (Test Site No. 5)

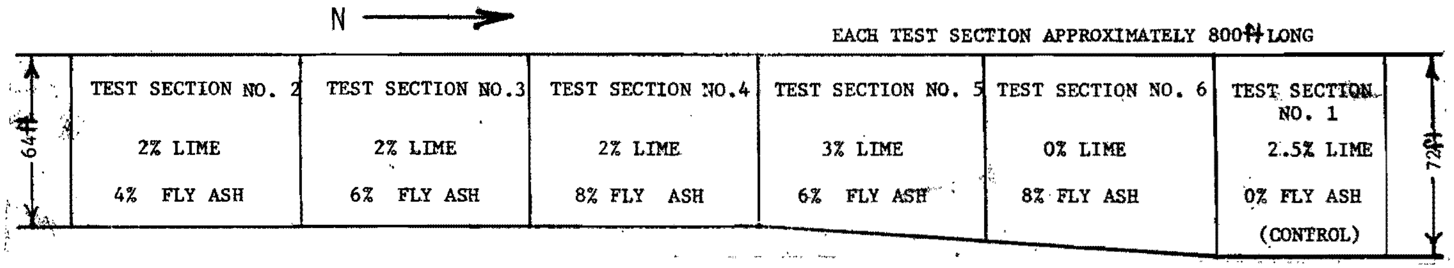


Figure A-11. Layout Planview of Test Sections on SH 335 in Potter County, Texas (Site No. 8)

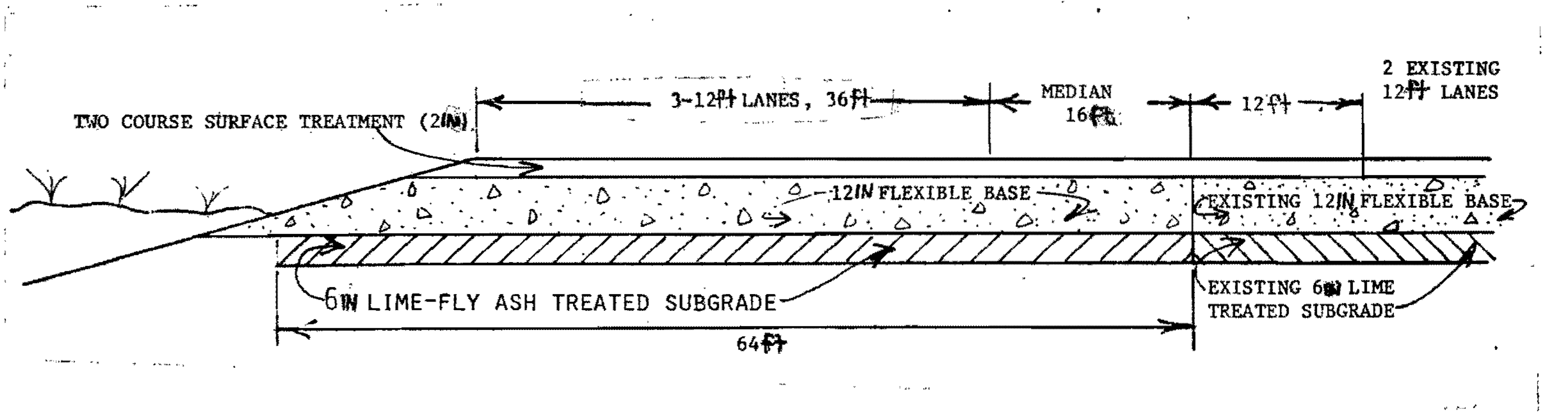


Figure A-12. Typical Section on SH 335 in Potter County, Texas (Site No. 8)

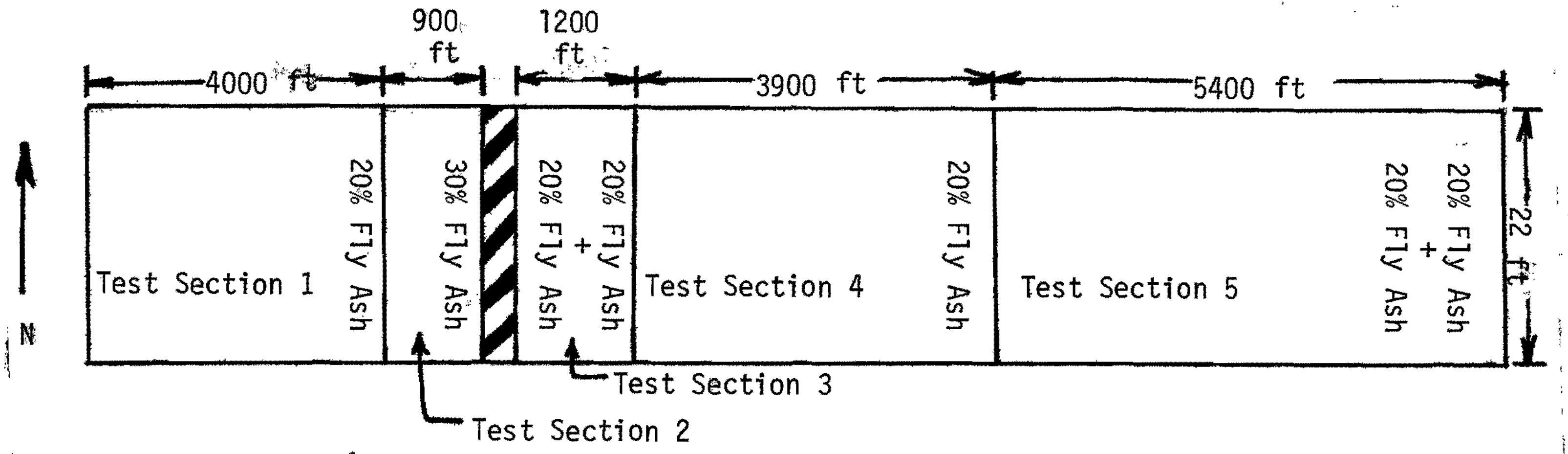


Figure A-13. Layout Planview of Test Sections on FM 2697 in Wheeler County, Texas (Test Site No. 12)

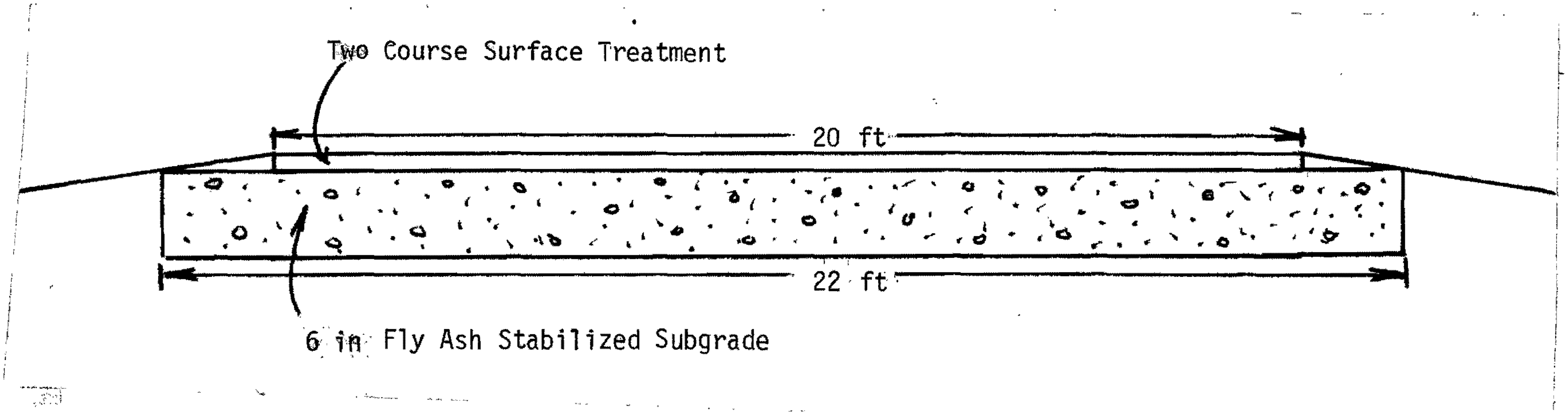


Figure A-14. Typical Section of FM 2697 in Wheeler County, Texas (Test Site No. 12)

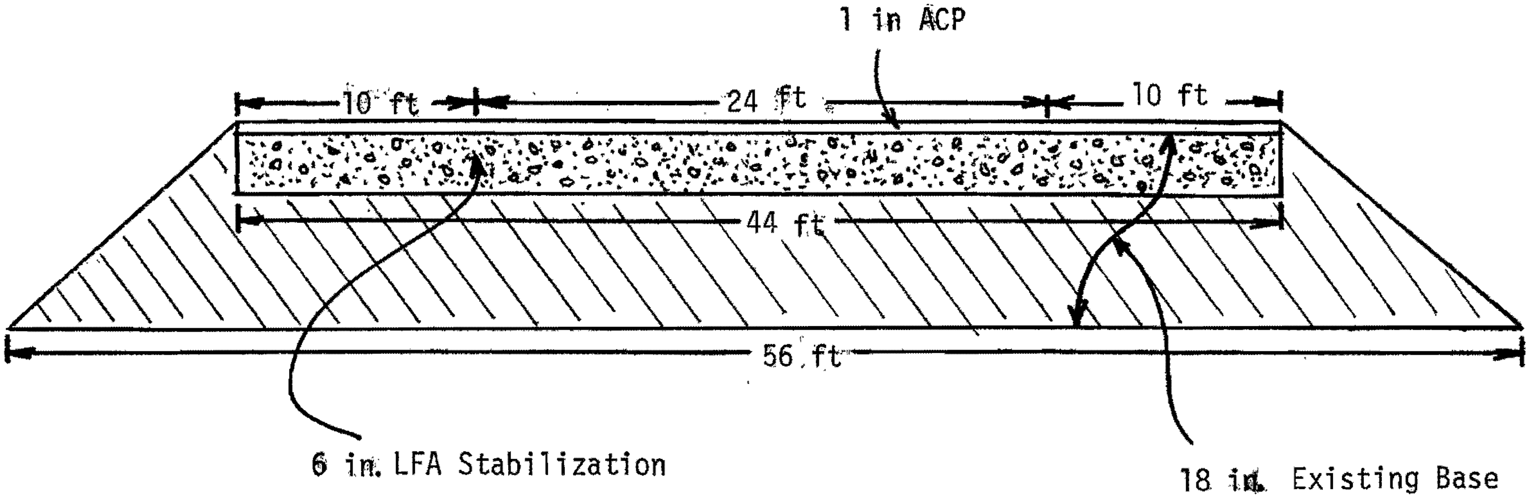
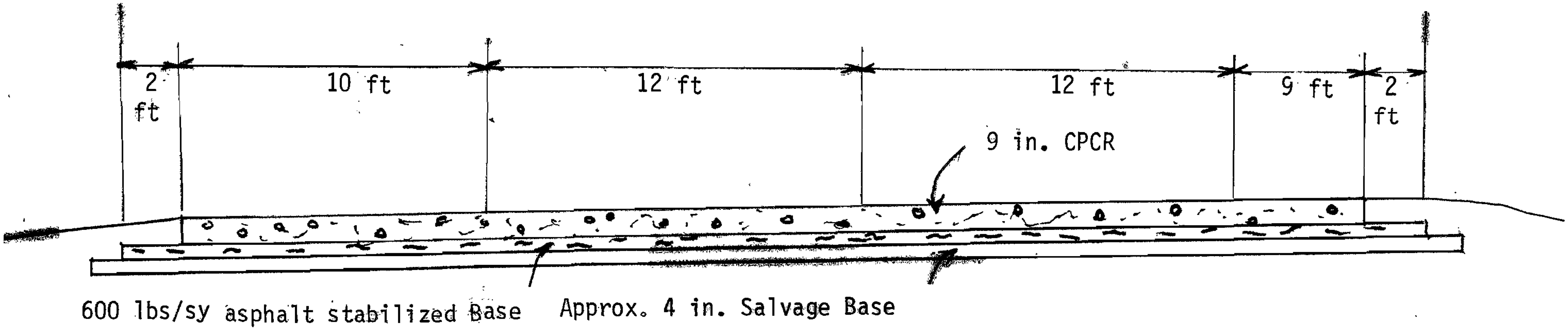
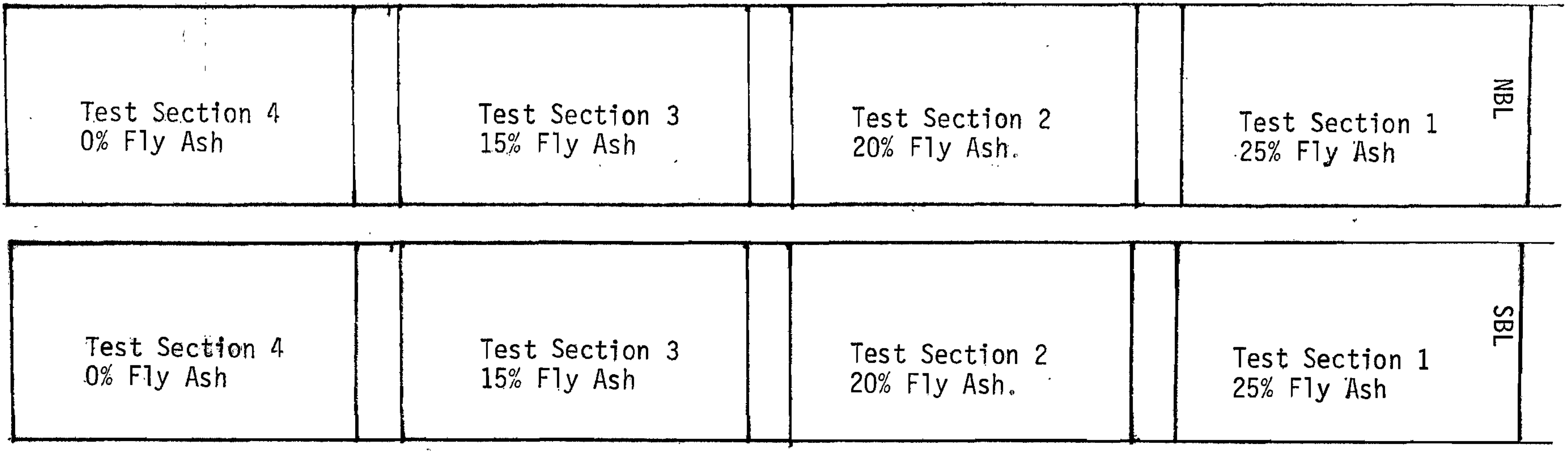


Figure A-15. Typical Section of US 87 Near San Antonio, TX (Test Site No. 13)



South Bound Lane

Figure A-16. Typical Section of IH 27 in Hale County, Texas (Test Site No. 9)



Test Section 4 0% Fly Ash	Test Section 3 15% Fly Ash	Test Section 2 20% Fly Ash.	Test Section 1 25% Fly Ash	NBL
Test Section 4 0% Fly Ash	Test Section 3 15% Fly Ash	Test Section 2 20% Fly Ash.	Test Section 1 25% Fly Ash	SBL

Figure A-17. Layout of test sections on IH 27 in Hale County, Texas (Test Site No. 9)

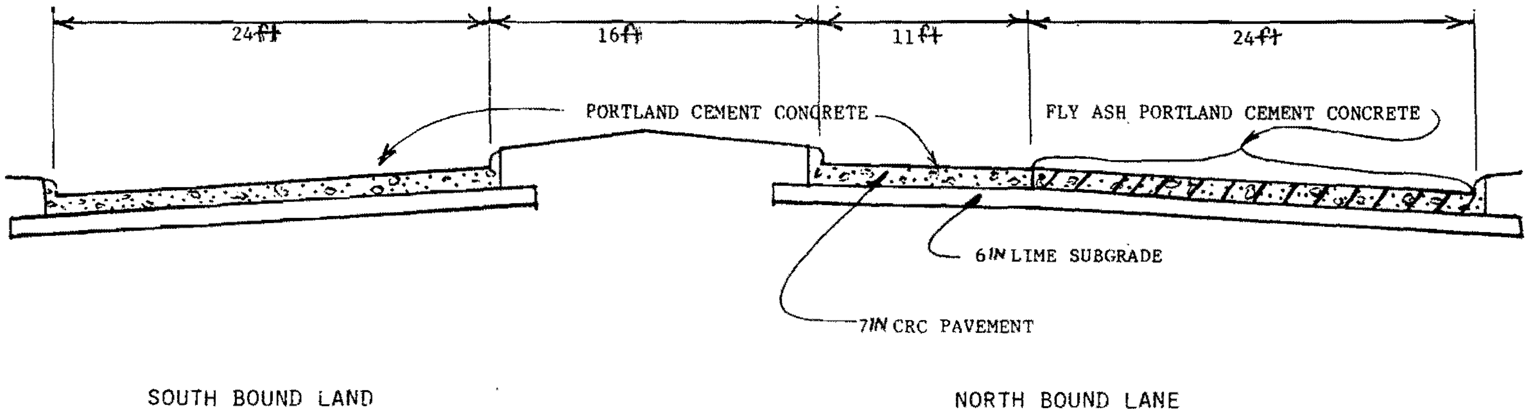


Figure A-18. Typical Section of Scott Street with Left Turn Lane in Houston, Texas (Site No. 10)

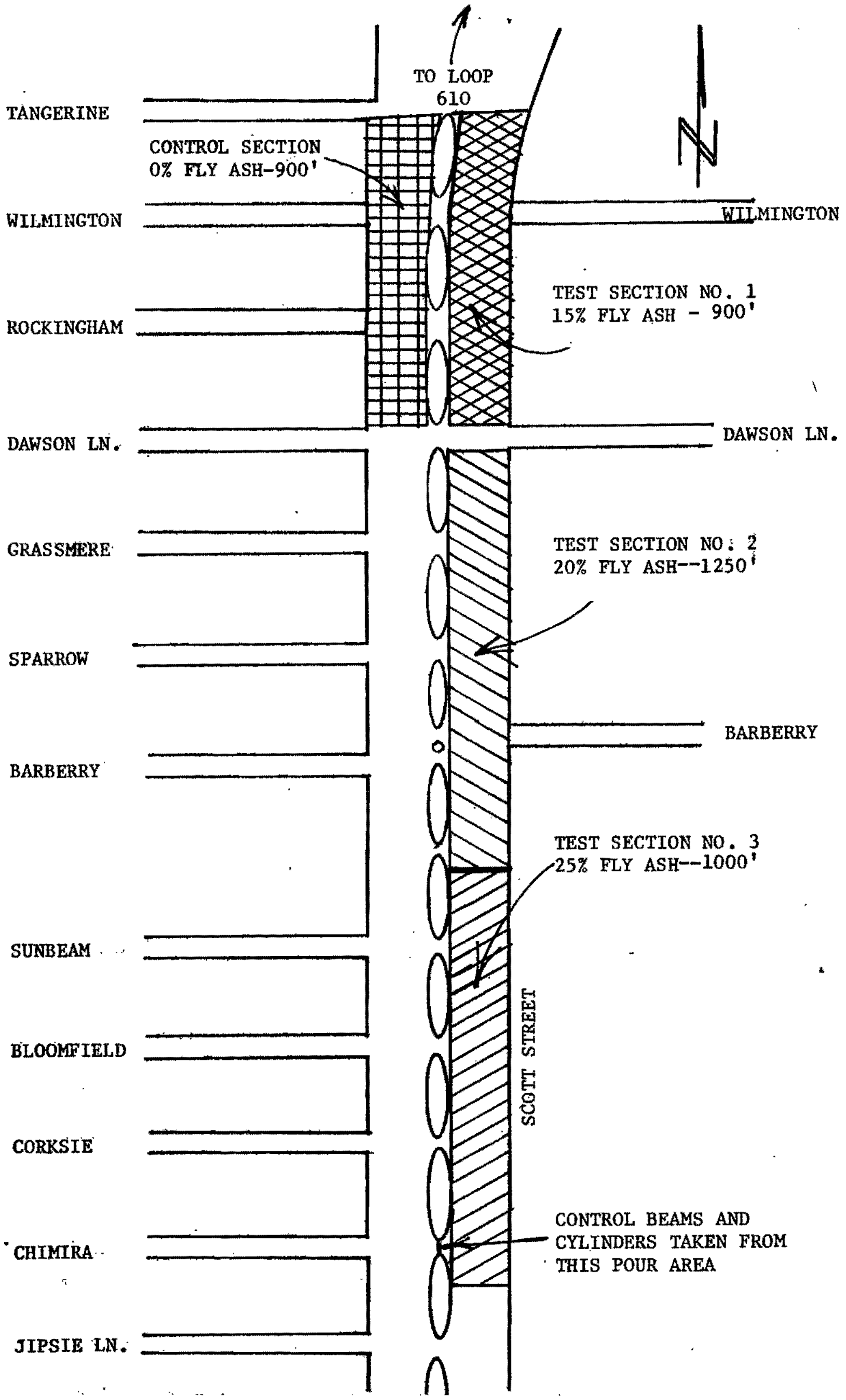


Figure A-19. Layout Planview of Test Sections on Scott Street in Houston, Texas (Site No. 10)

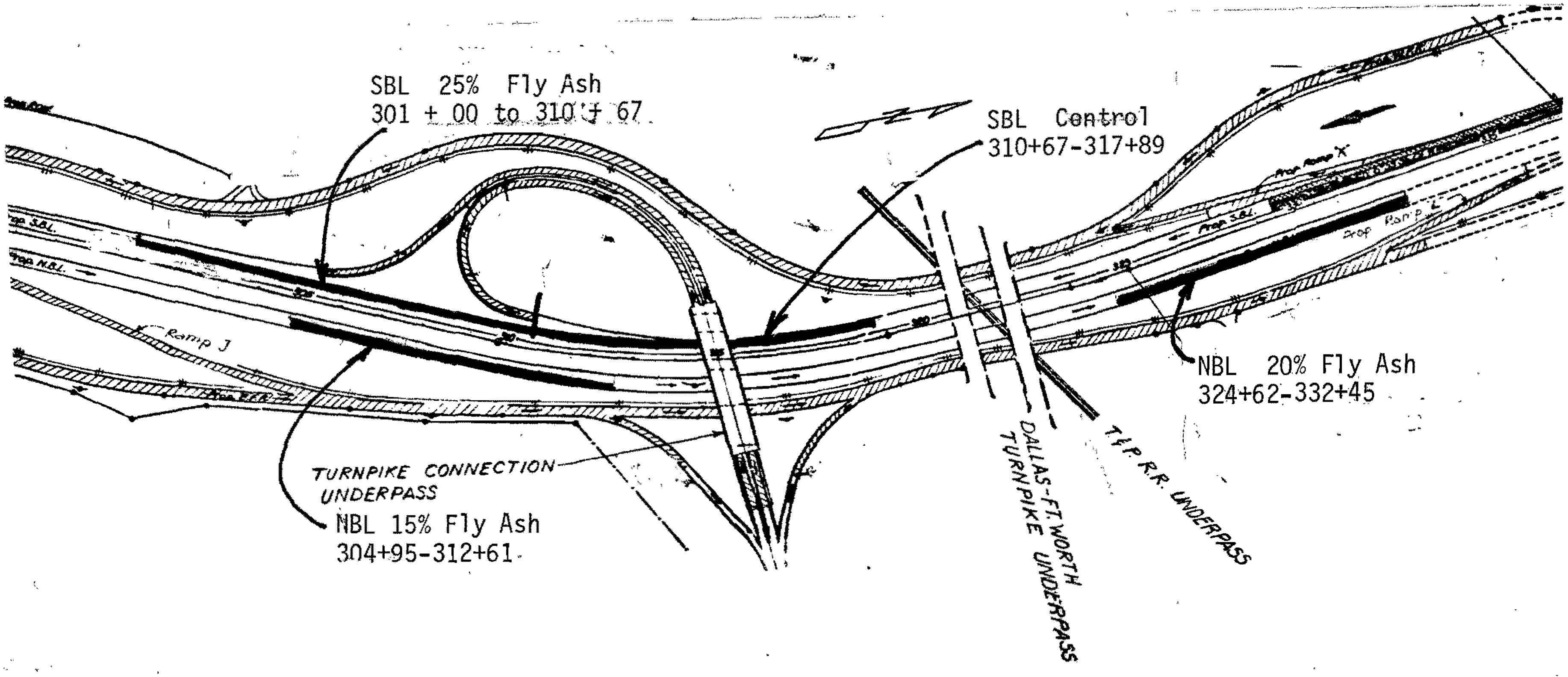


Figure A-20. General Layout of Test Sections US 80, Loop 12, Dallas County, Texas (Test Site No. 11)

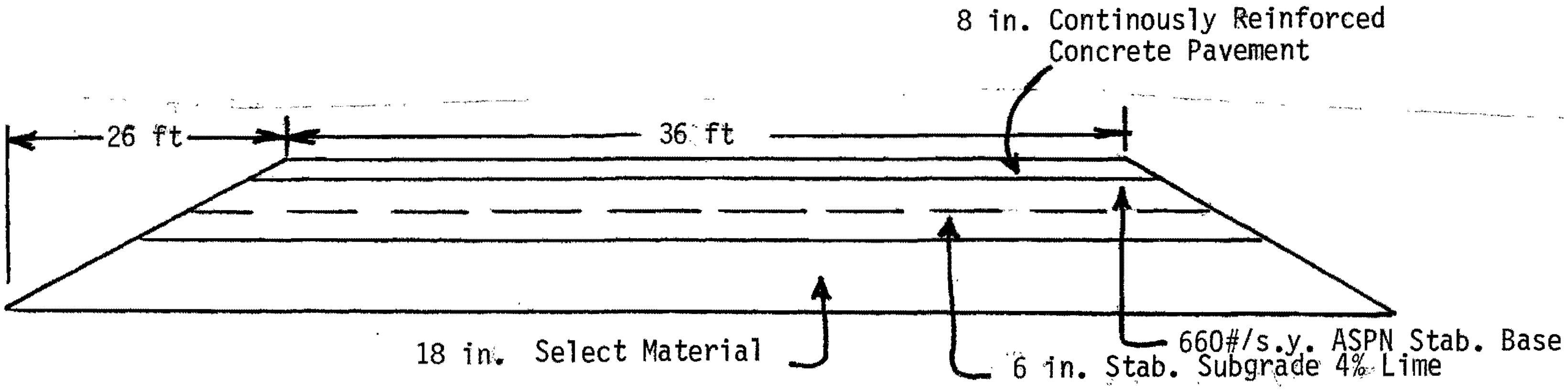


Figure A-21. Typical Section of US 80, Loop 12, Dallas County, Texas (Test Site No. 11)

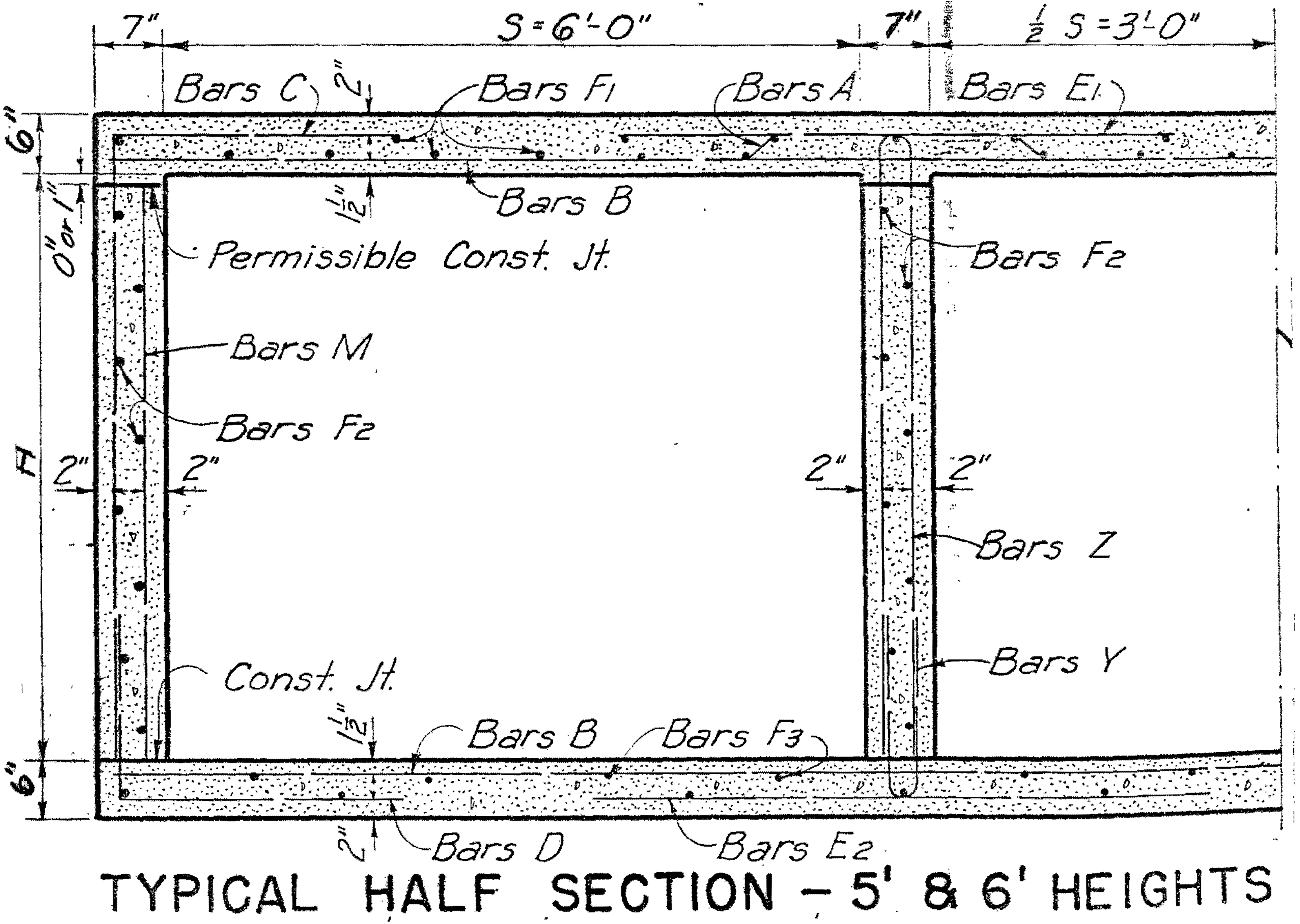


Figure A-22. Typical Half Section of Box Culverts on FM 1604 in Bexar County (Test Site 13)

Table A-1. Equipment Spread for FM 3378 in Bowie County, Texas (Test Site No. 1)

Equipment	Number Used	Manufacturer
Road Mixer	1	Rex
Road Mixer	2	Brose
Tamping Roller	1	TEX
Pneumatic Roller	2	Ingram
Motor Grader	2	Caterpillar
Water Truck	2	- -

Table A-2. Equipment Spread for US 59 in Panola County, Texas (Test Site No. 2)

Equipment	Number Used	Manufacturer
Road Mixer	1	Roy Go Gator
Sheepsfoot Roller	1	Ferguson
Pneumatic Roller	1	Ingram
Motor Grader	1	Caterpillar
Water Truck	1	- -

Table A-5. Equipment Spread for FM 1604 in Bexar County, Texas (Test Site No. 5)

Equipment	Number Used	Manufacturer
Road Mixer	1	Brose
Hyster Compactor	1	Caterpillar
Pneumatic Roller	1	Ingram
Motor Grader	1	Caterpillar
D-8 Dozer	1	Caterpillar
Disk Plow	1	Rhome
Water Truck	2	--

Table A-6. Equipment Spread for SH 335 in Potter County, Texas (Test Site No. 8)

Equipment	Number Used	Manufacturer
Road Mixer	1	Koeing
Road Mixer	1	Rex
Pneumatic Roller	3	Ferguson
Tamping Roller	2	Rex
Motor Grader	1	Caterpillar
Disk Plow	2	Rhome
Water Wagon	3	Caterpillar

Table A-7. Equipment Spread for FM 2697 in Wheeler County, Texas (Test Site No. 12)

Equipment	Number Used	Manufacturer
Road Mixer	1	Bumag
Vibratory Compactor	1	Ray Go
Pneumatic Roller	1	Caterpillar
Motor Grader	1	Caterpillar
Water Truck	2	- -

Table A-8. Equipment Spread for US 87 in Wilson County, Texas (Test Site No. 13)

Equipment	Number Used	Manufacturer
Road Mixer	1	Brose
Vibratory Compactor	1	Ray Go
Sheepsfoot Compactor	1	Caterpillar
Pneumatic Roller	1	Ingram
Water Truck	2	--

Table B-1. Average[a] Chemcial Analysis of Power Plant Fly Ash[b] (weight percent)

Oxide	Power Plant D	M	W	H	B	P	Specification
Silicon Dioxide as SiO_2	40.58	60.34	34.60	35.62	49.44	35.51	-
Aluminum Oxide as Al_2O_3	24.53	25.31	23.92	23.21	17.30	22.79	-
Iron Oxide as Fe_2O_3	5.01	3.36	5.53	6.31	7.36	7.22	-
Total SiO_2, Al_2O_3, Fe_2O_3	70.12	89.01	64.05	65.14	74.1	65.52	50.00 (min)
Calcium Oxide as CaO	23.66	8.66	26.80	26.50	18.25	28.53	-
Magnesium Oxide as MgO	3.74	2.06	4.24	4.16	3.46	3.39	5.00 (max)
Sulfur Trioxide as SO_3	1.25	0.11	2.78	2.33	1.44	1.93	5.00 (max)
Rapid Alkali							
Na_2O	0.50	0.02	0.97	0.79	0.17	0.25	-
K_2O	0.14	0.01	0.16	0.18	0.02	0.14	-
Na_2O (Equivalent)	0.60	0.03	1.07	0.91	0.18	0.34	1.50 (max)
Total	100.01	99.90	100.07	100.01	97.62	100.10	-
Retained No. 325 Sieve	18.8	36.18	15.08	15.78	15.90	19.9	34.0 (max)
Loss on Ignition	0.31	0.09	0.38	0.35	0.41	0.44	6.0 (max)

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[a] Average of four values, [b] ASTM C 311 - Weight Percentages, [c] ASTM C 618 - Weight Percentages

Table B-2, Summary of Fly Ash Variability Data

Test	Plant D	Plant D (Processed)	Plant M	Plant W	Plant H	Plant B	Plant P	ASTM C618-Class C Limits
Retained on No. 200-%								
Avg.	8.9	8.7	14.0	7.7	7.2	6.6	10.0	-
Std. Dev.	2.0	3.1	1.6	2.4	1.4	0.2	2.3	-
Coef. Var.	22.8	35.2	11.7	30.6	20.2	2.3	23.1	-
Retained on No. 325-%[a]								
Avg.	17.9	17.3	19.6	15.8	15.8	15.9	25.0	34.0 % max. with
Std. Dev.	2.5	4.7	3.3	4.2	2.5	2.5	3.7	5% points max.
Coef. Var.	14.0	27.0	11.2	26.1	15.7	15.5	14.6	Variation
% failing to meet limits	2.0	15	7	27	4	2	24	
Specific Gravity-								
Avg.	2.57	2.56	2.27	2.60	2.61	2.56	2.75	5% points max.
Std. Dev.	0.06	0.04	0.03	0.04	0.03	0.03	0.01	variation
Coef. Var.	2.11	1.50	1.53	1.35	1.12	1.17	0.36	
% failing to meet limits	0	0	0	0	0	0	0	
Loss On Ignition-%								
Avg.	0.28	-	0.27	0.29	0.31	0.41	0.44	6% max.
Std. Dev.	0.03	-	0.02	0.02	0.04	0.12	0.22	
Coef. Var.	9.4	-	5.9	6.8	30.8	28.8	50.0	
% failing to meet limits	0	0	0	0	0	0	0	

[a] Results furnished by vendor

Appendix C. DHT Lime-Fly Ash Specification

SPECIAL SPECIFICATION

LIME, LIME-FLY ASH (LFA) OR FLY ASH (FA)
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/or 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, Commerical Lime Slurry is specified, the Contractor shall select, prior to construction, the grade to be used and 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 Pavement (Water Cement Ratio)."

(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 lime-fly ash or fly ash 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 lime,LFA or FA mixture, free from loose or segregated areas, of uniform moisture content, well bound for its full depth and with a surface finish suitable for placing a surface course. It shall be the responsibility of the Contractor to regulate the sequence of his work, to use the proper amount of lime and/or fly ash, maintain the work and rework the courses as necessary to meet the above requirements.

Prior to beginning any lime, LFA or FA treatment, in cuts and fills, the roadbeds shall be constructed and shaped to conform to the typical sections, lines, and grades as shown on the plans or as established by the Engineer.

(2) Preparation of Roadbed. Before other operations are begun, the roadbed shall be graded and shaped as required to construct the lime, lime-fly ash, or fly ash 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 or fly ash shall be spread only on that area where the first mixing operation can be completed during the same working day.

The sequence for application of lime and fly ash shall be as specified below in Section 4.(4)B.

The application and mixing of lime or fly ash 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 or fly ash 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 or fly ash shall be distributed at a uniform rate and in such manner as to reduce the scattering of lime or fly ash by wind to a minimum. Lime or fly ash shall not be applied when wind conditions, in the opinion of the Engineer, are such that blowing lime or 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 or fly ash 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 or fly ash 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 or fly ash content has been secured. The distributor vehicle shall be equipped with an agitator which will keep the lime or fly ash and water in a uniform mixture.

(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, disking, harrowing, scarifying or the use of other approved pulverization methods.

In the layer of deep treatment specified as the base, the mixing shall reduce the clods, 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

In the base layer, additional lime, and/or fly ash application, is started immediately after the lime modified material has passed the above grading requirement. The time between the initial lime application and the application of additional lime and/or fly ash application shall not exceed 4 calendar days. This application shall be applied only to such areas that all the operations can be continuous and completed in daylight within 6 hours of such application.

If the material to be stabilized with lime-fly ash 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.

C. Mixing Procedure for Fly Ash Only. If fly ash only is to be used without lime, the following mixing procedures shall apply.

The raw material 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 is obtained, free from all clods or lumps.

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

The material and fly ash 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 is obtained, free from all clods or lumps. If the soil binder-fly ash mixture contains clods, they shall be reduced in size by raking, blading, discing, harrowing, scarifying or the use of other approved pulverization methods.

In the layer of deep treatment specified as the base, the mixing shall reduce the clods 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 shall be applied only to such an area that all the operations can be continuous and completed in daylight within 6 hours of such application.

During the interval of time between application and mixing, 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.

Mixing after the addition of fly ash will be accomplished dry or with a minimum of water to prevent fly ash balls.

(5) Compaction. Compaction of the mixture shall begin immediately after final mixing and in no case later than 3 calendar days after final mixing, unless approval is obtained from the Engineer. The material shall be aerated or sprinkled as necessary to provide the optimum moisture. Layers under two (2) feet compacted thickness may be compacted in one operation. The material shall be sprinkled or dried when necessary to provide the moisture for proper compaction. Compaction shall continue until the entire depth of mixture is compacted to a satisfactory condition as demonstrated by proof rolling with the further requirement that the top eight (8) inches of the uppermost course of the mixture shall be compacted to not less than 95% of the density as determined by the compaction ratio method, unless otherwise shown on the plans. Testing of this top eight inches will be in accordance with Test Method Tex-114-E. The Engineer may require it to be reworked as necessary to meet these requirements or require the Contractor to change his

his construction methods to obtain the 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 surface course is placed or the work is accepted, it shall be recompacted and refinished at the sole expense of the Contractor.

When Proof Rolling is included in the plans, the Engineer will direct the application of proof rolling to sections where compaction has been completed.

(6) Finishing, Curing, and Preparation for Surfacing. After the final layer or course of the lime, lime-fly ash, or fly ash treated subgrade, subbase or base has been compacted, it shall be brought to the required lines and grades as determined by the Engineer.

A. The resulting base surface shall be thoroughly rolled with a 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 and line shown on the plans.

B. After the lime, lime-fly ash or fly ash treated course has been finished as specified herein, the surface shall be protected against rapid drying by either of the following curing methods for a period of not less than 3 days or until the surface or subsequent courses are placed:

a. Maintain in a thorough and continuously moist condition by sprinkling.

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

c. 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 the Contractor elects to use this method, 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.

d. Where the finish surface is to be treated with prime and surface treatments, the prime coat may be used as a curing membrane.

C. Completed sections of lime, lime-fly ash or fly ash 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 lime-fly ash or fly ash treated course has hardened sufficiently to prevent marring or distorting the surface by equipment or traffic.

5. MEASUREMENT. Lime, lime-fly ash or fly ash treatment of the subgrade, existing subbase, existing base, and existing materials shall be measured by the square yard to neat lines and depths 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 shall 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 of 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 of 2,000 pounds for "Fly Ash" which price shall be full compensation for furnishing all fly ash.

"Lime, LFA, FA Treated Subgrade (Density Control)", "Lime, LFA, FA Treated Existing Subbase (Density Control)", and "Lime, LFA, FA Treated Existing Base (Density Control)" will be paid for at the unit price bid per square yard.

"Lime, LFA, FA Treated Existing Materials (Density Control)" will be paid for at the unit price bid per square yard.

The unit price bid shall be full compensation for loosening, mixing, pulverizing, spreading, drying, application of lime, application of fly ash, water content of the slurry, shaping and maintaining; for all curing including all curing water and/or other curing materials; for all manipulations required including processing for adding additional treatment materials to base layers; for all hauling and freight involved; for all tools, equipment, labor, and for all incidentals necessary to complete the work except as specified.

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.

When "Prime" is used for the curing membrane, all prime and sand used will be measured and paid for in accordance with the provisions governing the item "Prime Coat (Asphaltic Materials and Sand)".

When "Proof Rolling" is used, all rolling directed by the Engineer will be measured and paid for in accordance with the provisions governing the item "Rolling (Proof)".

Appendix D. GUIDELINES FOR THE USE OF FLY ASH IN HIGHWAY CONSTRUCTION

D - 1 Introduction

The purpose of these guidelines is to present the state-of-the-art in constructing highways using fly ash. These guidelines are the result of an ongoing laboratory and field investigation of selected Texas fly ashes. Even though the research study is not yet complete, the guidelines have been prepared to meet the need to proceed with fly ash utilization in order to achieve the economic and energy benefits acruing from such use. The approach used in preparing these guidelines has been a conservative one. Where data are available we can recommend with confidence. Where data are not available, we can still recommend with confidence, so long as we maintain adequate factors of safety. These guidelines contain adequate factors of safety and with increased knowledge - recommeded limits may be reduced in the future.

D - 2 Stabilization of Clay and Silty-Clay Subgrade Soils

Soils with a plasticity index (PI) of greater than around 10 with little or no sand sized particles (greater than No. 200 sieve) fall into this category. These soils are generally a triaxial class of 3.0 or greater. In order to adequately stabilize these materials, optimum amounts of lime, fly ash and moisture should be determined through laboratory investigations. Based on the laboratory results the following steps are recommended:

1. A minimum of 1 1/2 percent Type A hydrated lime should always be used to break down the clay.
2. The soil should be scarafied to the required depth.
3. The lime and enough water to reach optimum moisture should be added and thoroughly mixed with a pulver mixer until the material is free of lumps or clods.

4. The pulverized section should be al
minimum of 48 hours prior to furthe
time for lime to begin to react wit
this curing period the material should be kept moist.

5. Because most Texas fly ashes possess cementitious properties (in addition to pozzolanic properties) which occur very rapidly in a manner similar to portland cement, the fly ash must be applied in a dry form, mixed dry, then watered and remixed, and finally compacted. The entire procedure should be completed in not more than six hours.

5.1. To reduce dusting during fly ash application (Figure D-1) you may a) lower discharge pressure of the fly ash to 1 to 3 psi b) utilize a specially designed spray bar system (Figure D-2), c) house the discharge in a canvas "tent" or "shroud" (Figure D-3). Operations many have to be suspended during high winds.

5.2. Initial dry mixing of the fly ash with the soil should be accomplished with a disc plow or motor patrol (not a pulver mixer) in order to reduce dusting (Figure D-4 and D-5). This should be followed by the addition of water to reach optimum moisture.

5.3. Final mixing should be accomplished with the pulver mixer (Figures D-6 and D-7) until a minimum of 60% of the soils will pass the No. 4 sieve.

5.4. The mixed soil should be compacted (Figure D-8) with sheepsfoot compactors and/or with vibratory compactors (Figure D-9) until a minimum of 95% of laboratory density is obtained (Test Method Tex 114-E).

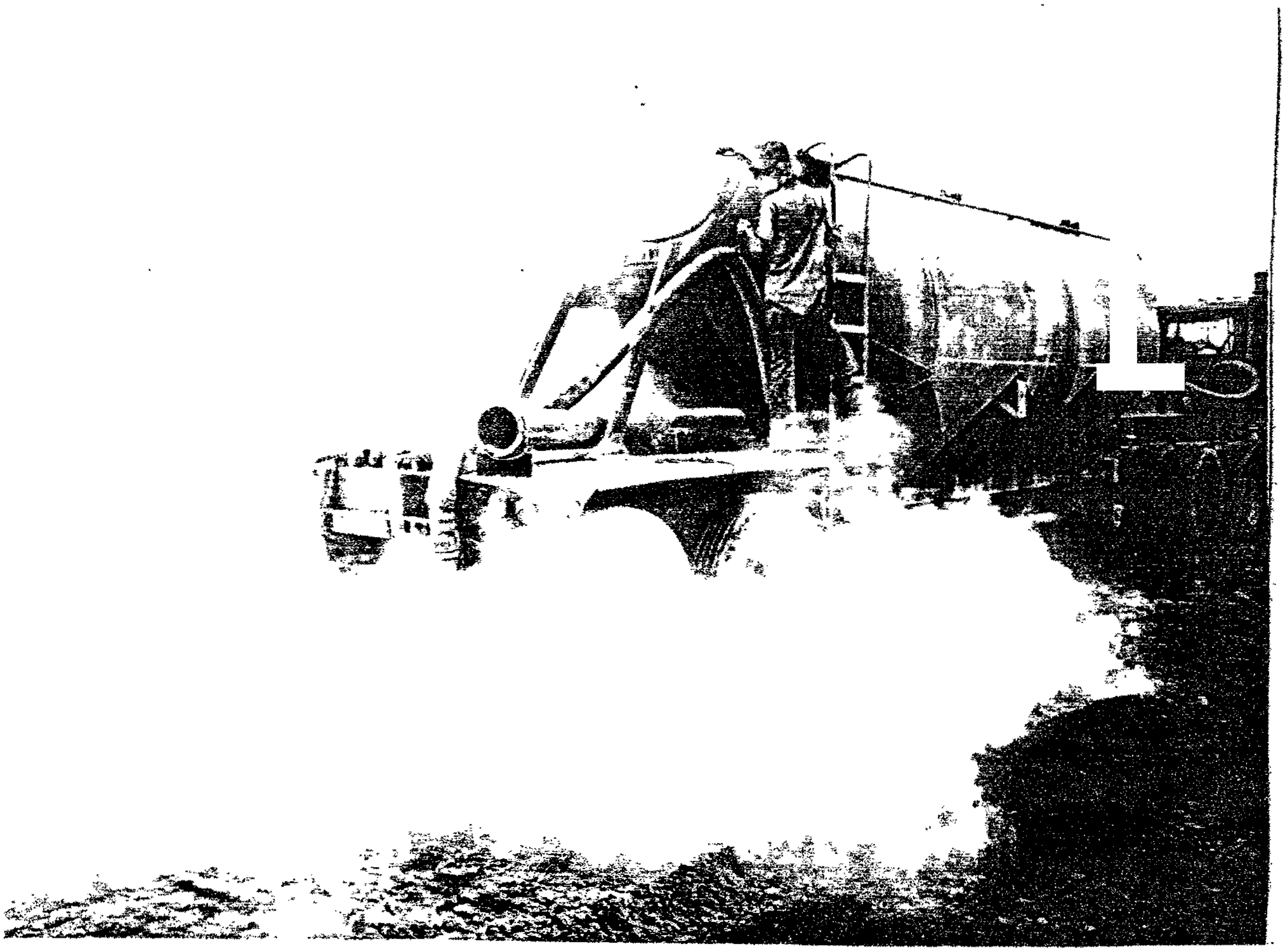

Figure D-1. Photograph Showing Problem of Dusting with Fly Ash Stabilization (Note Mask on Worker).

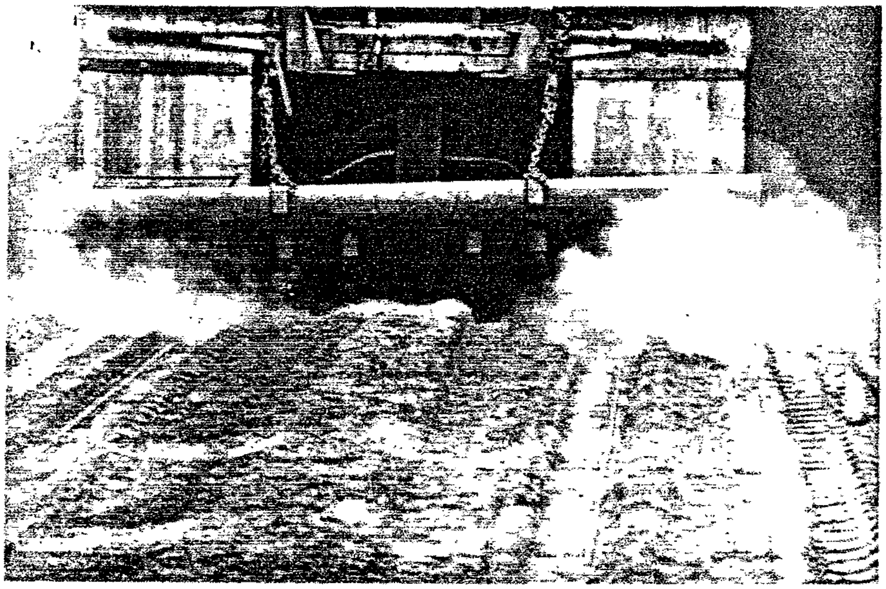

Figure D-2. Closeup View Showing Dust Reduction Techniques of Lowering Nozzles of Transport Truck.

Figure D-3. Photograph Showing Reduction in Dusting with use of Canvas Drag, Lowered Nozzles and Low Pressure.

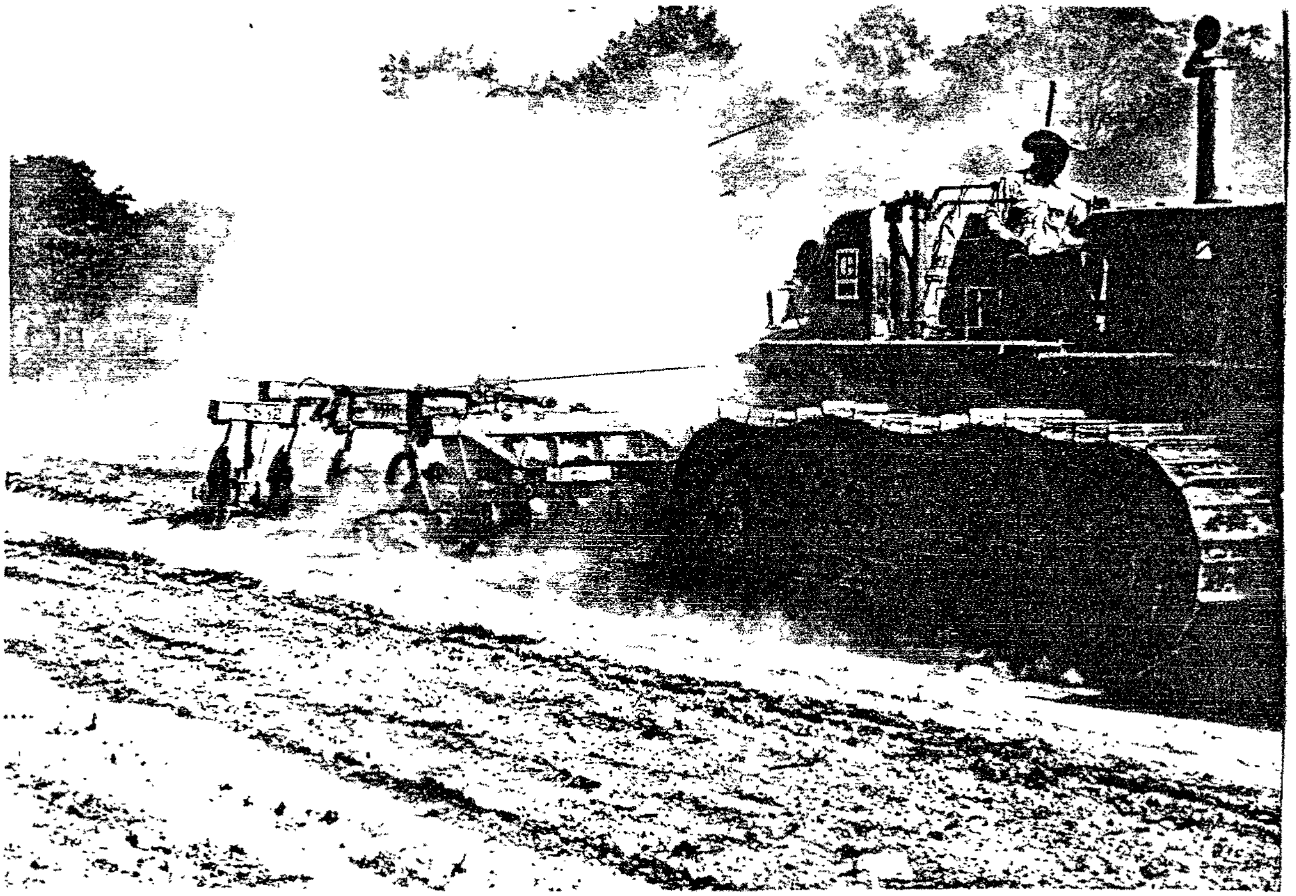

Figure D-4. Disk Plow being Pulled by Dozer to Initially Mix Fly Ash with Soil.

Figure D-5. Motor Patrol Initially Mixing Fly Ash with Soil.

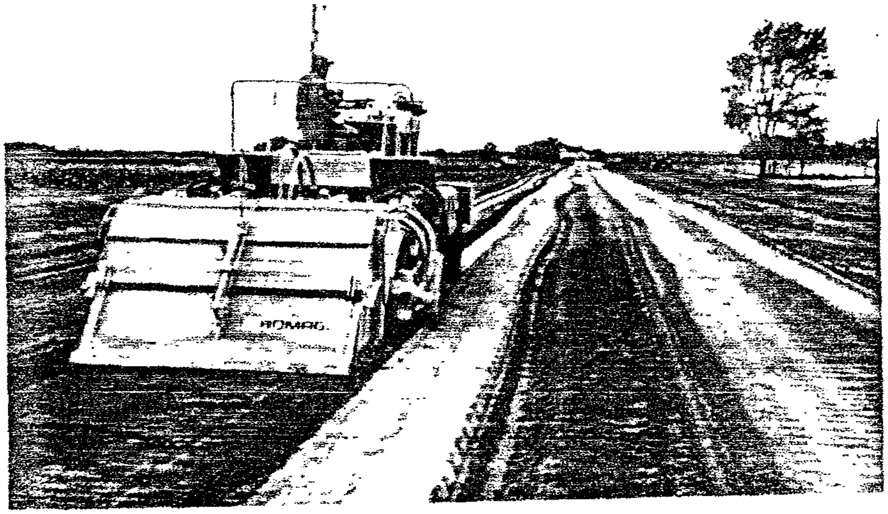

Figure D-6. Multiple Transverse Shaft Rotary Mixer (Flat Type).

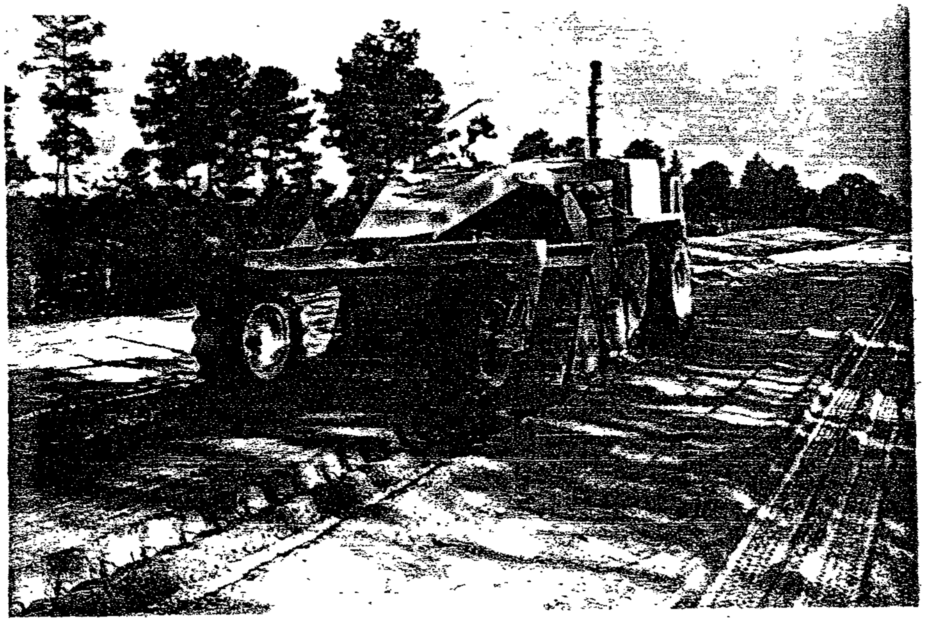

Figure D-7. Single Transverse Shaft Rotary Mixer.

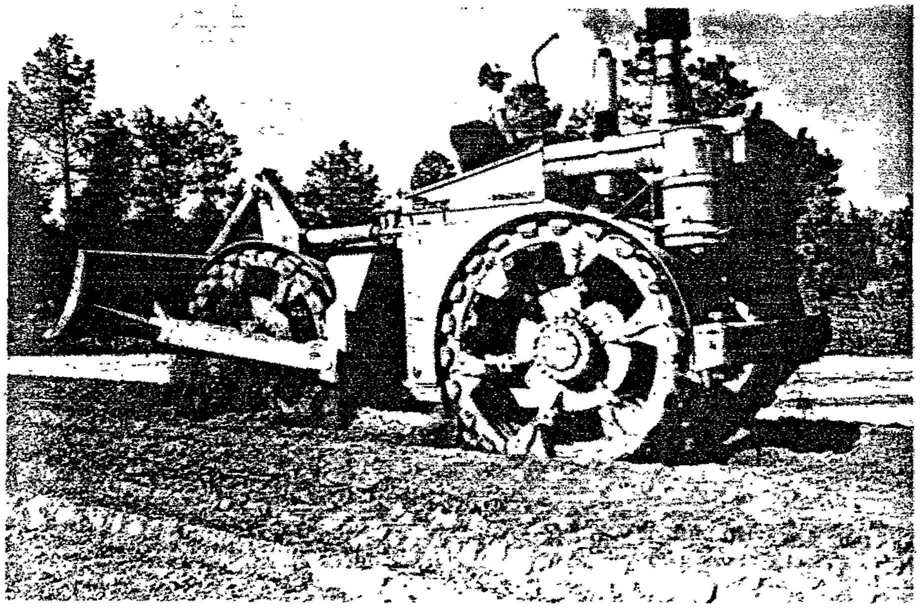

Figure D-8. Compaction Using Sheepsfoot Roller.

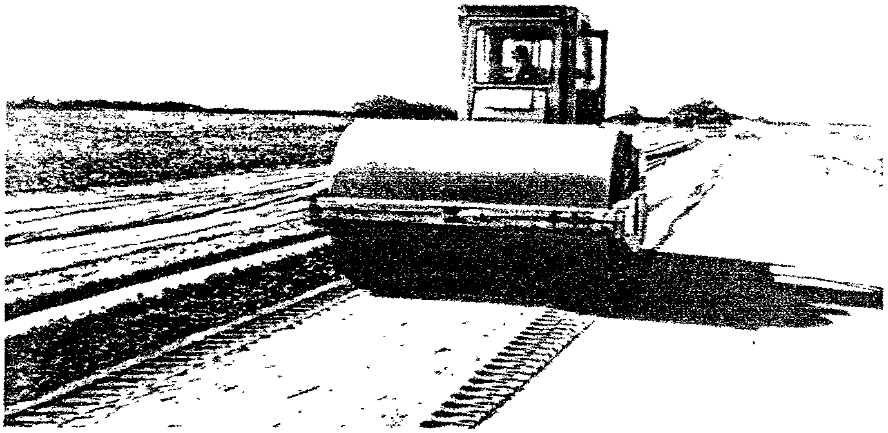

Figure D-9. Compaction Using Vibratory Compactor.

5.5. Under no conditions must the progress of work be delayed beyond the six-hour maximum time limit.

5.6. After final compaction, the completed sections should be immediately brought to final grade and cured until the next course is applied. SURFACE REWORKING AFTER COMPLETION SHOULD NOT BE PERMITTED, as the cementitious advantages of the fly ash will be lost.

5.7. Heavy construction traffic should not be permitted on the stabilized section for a minimum of 14 days.

D - 3 Stabilization of Sandy Soils and Flexible Bases

To stabilize these materials (PI should be less than around 5), the primary function of the fly ash is to act in a similar manner as portland cement, (i.e., to cement the soil particles together). Thus, successful stabilization may be achieved with fly ash alone, (without using any lime or portland cement) although such designs do not take full advantage of the pozzolanic reaction between the lime and the fly ash. Mix designs should be based on laboratory investigations to select the optimum amounts of fly ash and water (and either lime or portland cement if needed). If lime is used, the construction procedures are essentially the same as enumerated in section D-2. If fly ash or fly ash and portland cement are used, Steps 1 through 4 can be eliminated, and the fly ash and portland cement placed together in Step 5.

D - 4 Fly Ash-Portland Cement Concrete Construction

In this type of construction the fly ash is used as a partial replacement for the portland cement. Replacement amounts and recommeded mix designs should be determined through a laboratory investigation, using the specific materials proposed for the job. Existing specifications for strength requirements, construction equipment, and construction procedures are quite complete and no changes are needed when fly ash is used.

The only differences in the resulting concrete are a) a slightly "stickier" mixture is produced which can be offset by using a little more air entrainment and b) a slightly longer setting time may occur. The longer setting time should be carefully monitored to insure that surface texture is applied at the optimum time.

If the fly ash is added at a ready mixed concrete plant from a separate silo and then mixed in a ready mixed concrete truck while enroute, the inspector should be cautioned to watch for trucks leaving the plant without receiving the fly ash.