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April 1987

Ammonium Phosphate/Fly Ash Road Base Construction

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and
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Construction Report

report

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College of Engineering
Iowa State University

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Story County Engineer and
Department of Civil Engineering

engineering research institute
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INTRODUCTION

This project originated in Iowa DOT project HR-225, in which fly ash characterization led to the hypothesis that small amounts of inexpensive compounds could be found to control set and enhance strength of Iowa's fast setting, self-cementing fly ashes [1]. The validity of this hypothesis was demonstrated with support from a subsequent project, HR-260, in which fertilizer grade ammonium phosphate was found to produce strength increases of up to five-fold for some fly ashes, and also to increase set time from a few minutes to more than an hour [2,3]. The result was intended to be a low-cost yet strong roadway base stabilizer, particularly suited for areas where transportation costs of kiln dust, lime and portland cement are prohibitive.

Laboratory work suggested that ammonium phosphate-treated fly ash (APFA) may be as much as three times more cost effective than portland cement-treated base courses, the comparison being based on cost to realized strength. Evaluation of factors such as pavement stress, environmental deterioration, construction methods, and quality control were beyond the scope of HR-260, which was a laboratory, rather than field, evaluation; hence, evaluation of these factors represents the main objective of this project. Determining whether low cost aggregates such as crusher fines or unprocessed sands can be used with APFA forms a second, equally important, aspect of the present project.

BACKGROUND

Research preliminary to this project was done to provide a perspective on state wide application. Fly ashes available in Iowa can be ranked according to reactivity with ammonium phosphate as follows:

Rank	Source	Untreated Strength	Ammonium Phosphate Treated Strength
1	Lansing	2200 psi	3800 psi
2	Neal #4	1600	3600
3	Louisa	1230	2240
4	Ames	1300	2200
5	Ottumwa	320	500

It can be seen that Ames and Louisa ashes are similar intermediate performers with regard to ammonium phosphate reactivity. The use of Ames ash in this project offers an evaluation of intermediate performance. Ammonium phosphate concentrations for the above paste strengths ranged from 1.5 to 3 percent. Tricalcium aluminate content (C_3A) appears to be the primary factor determining reactivity. In general, higher tricalcium aluminate levels yield better performance; i.e., the more C_3A, the better.

Frost Action - One concern, and an unknown to be evaluated in this research, is the ability of an ammonium phosphate-treated fly ash base to withstand freezing and thawing. ASTM test C 666-84, Method A, is a test intended for concrete and is extreme in terms of the actual conditions existing in a stabilized base. Use of ASTM test C 666-84, Method A, in the present research subjected specimens to rapid freeze-thaw action for the purpose of evaluating the resistant ability of fly ash-crusher fines bases.

Tests performed in this research represent a conservative measure of freeze-thaw performance. The 12-cycle rapid freeze-thaw test simulates an Iowa winter. Results, measured in terms of residual compressive strengths and weight losses, are presented below:

Cement (%)	Initial Strength (psi)	Strength After Freezing (psi)	Weight Loss (%)
20	1502	652	0
25	1556	1004	6
30	2609	1048	0
35	1992	1520	0
40	2488	1484	0
45	2528	1657	0

Three-eighths inch limestone crusher fines from the Martin-Marietta quarry in Ames, Iowa were selected as typical of materials available throughout the state; Neal #4 fly ash was used. These data suggest ammonium phosphate/fly ash bases should meet or surpass established criteria.

Several criteria have been established for acceptable freeze-thaw performance of portland cement and lime fly ash stabilized base courses. For example, ASTM C 593 requires a minimum 400 psi compressive strength after freeze-thaw. The Portland Cement Association and AASHTO standards T 135-70 and T 136-70 for freeze-thaw performance are based on weight loss limitations of 7 to 14 percent.

Shrinkage - Shrinkage of portland cement stabilized subgrades has been acknowledged as a problem; for this reason, shrinkage evaluation for fly ash mixes was performed. Shrinkage samples were produced for ammonium phosphate-treated fly ash and crusher fines, as specified in ASTM C-157. The samples were first allowed to cure in a humidity room for 14 days at 77 degrees F, and then placed in a 100 degree F oven for 14 days. Measurements were taken for all samples every two days. In all cases, the 14-day cycle was sufficient time for stabilization of the specimen length. Shrinkage strain (percent x 10^{-3}) is as follows:

Fly Ash or Cement Content, %	Portland Cement	APFA
100	351.0	34.7
20	66.8	35.2
25	75.3	37.3
30	77.9	29.8
35	120.0	32.5

Fly ash specimens evidenced less than one-half the shrinkage of portland cement; this reduction could be significant to base stability and may be attributed to expansive fly ash hydration products which compensate for water loss.

Rate of Strength Gain - Of concern during construction is the rate of strength developed to support subsequent construction processes and opening of a road to traffic. The following strengths were measured in a preliminary evaluation of ammonium phosphate/fly ash with crusher fines:

Time	Compressive Strength (psi)
4 hrs	642
16	745
40	836
7 day	1023

These data indicate that a 30 percent fly ash mixture should be capable of supporting traffic after four hours, and the 642 psi strength generated by this mixture should be adequate for all but extreme loads.

SCOPE

Objective

The objective of this research was to evaluate construction and service performance of APFA treated base courses.

Research

The research involved construction of test sections in Story County to evaluate:

1. Use of APFA with crusher fines and/or "blow sand"--inexpensive aggregates which are readily available in many parts of the state.
2. Use of self-cementing Ames fly ash.
3. Development of construction specifications and standards necessary to construct APFA bases.
4. Evaluation of structural capabilities of APFA pavements to develop appropriate design methods (i.e., AASHTO structural layer coefficients/PCA flexural strength techniques).
5. Comparison of economic and technical performance of APFA bases with conventional materials.

The research project is located on a 1.77 mile granular surfaced section of R63 north of its intersection with E29 (Figure 1). The project involved 4500 feet (4 sections) of fly ash stabilized base, with the remainder of the construction being 6" of total depth asphalt. Preliminary design suggested the light traffic on this section could be accommodated by a fly ash stabilized base of 6", having a 1.5" asphalt surface. To accommodate evaluation of thickness and material variables, the following fly ash sections were proposed:

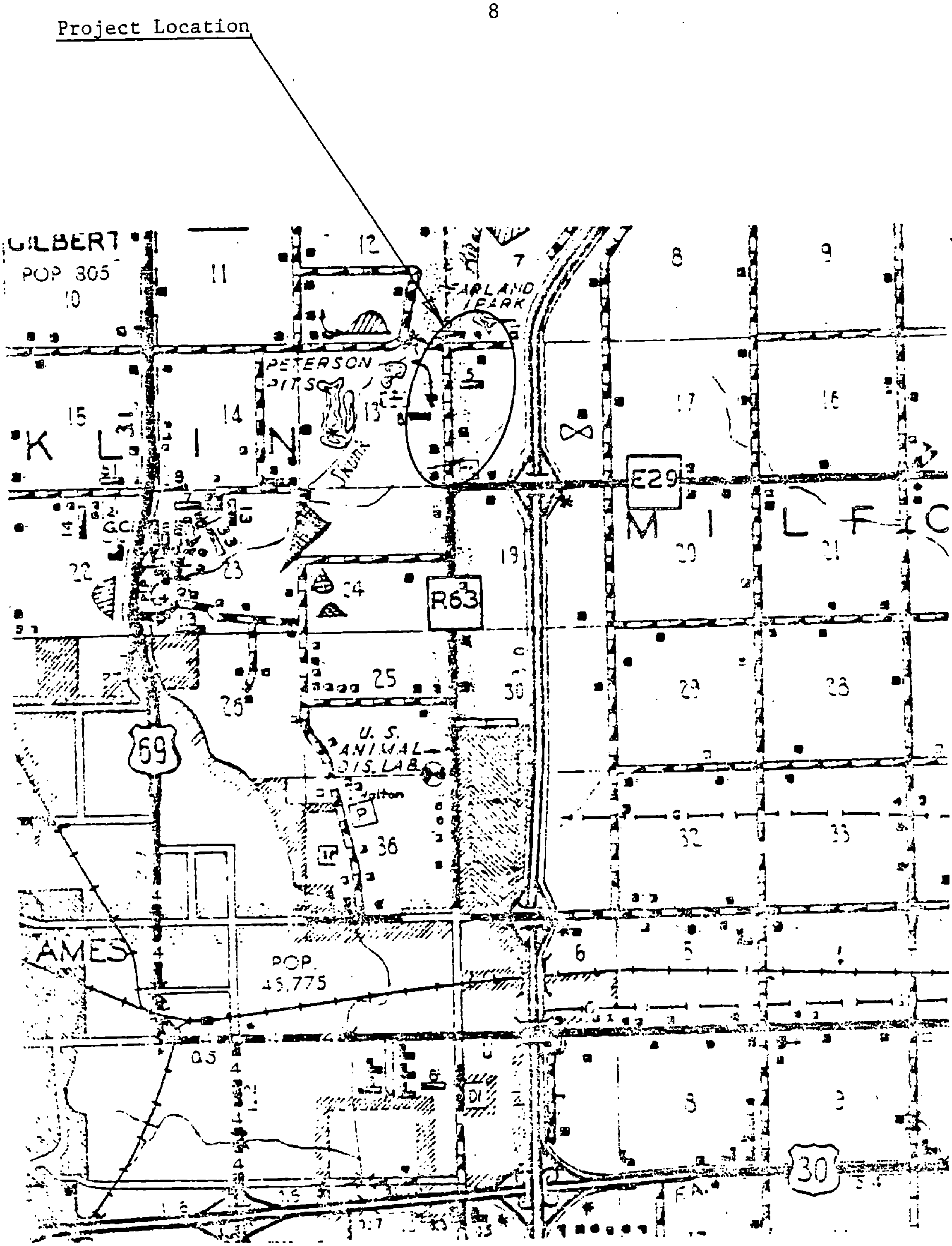
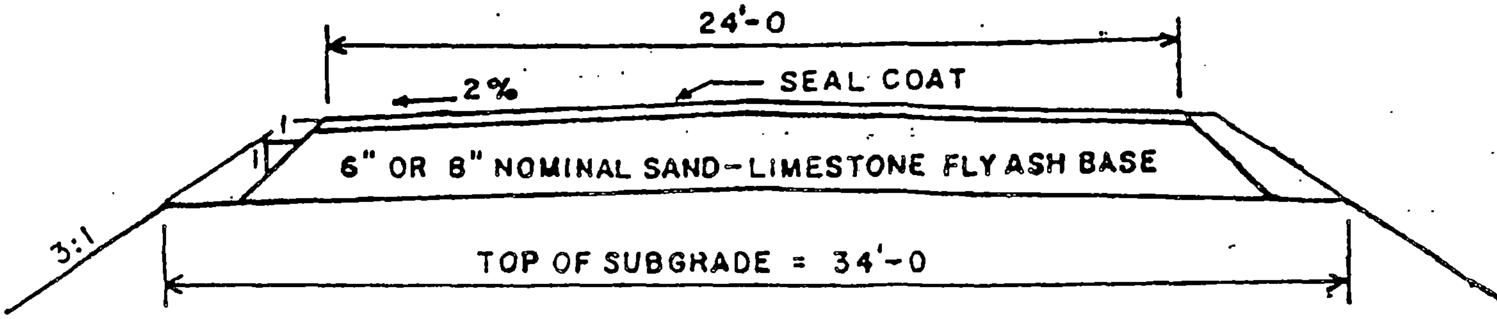


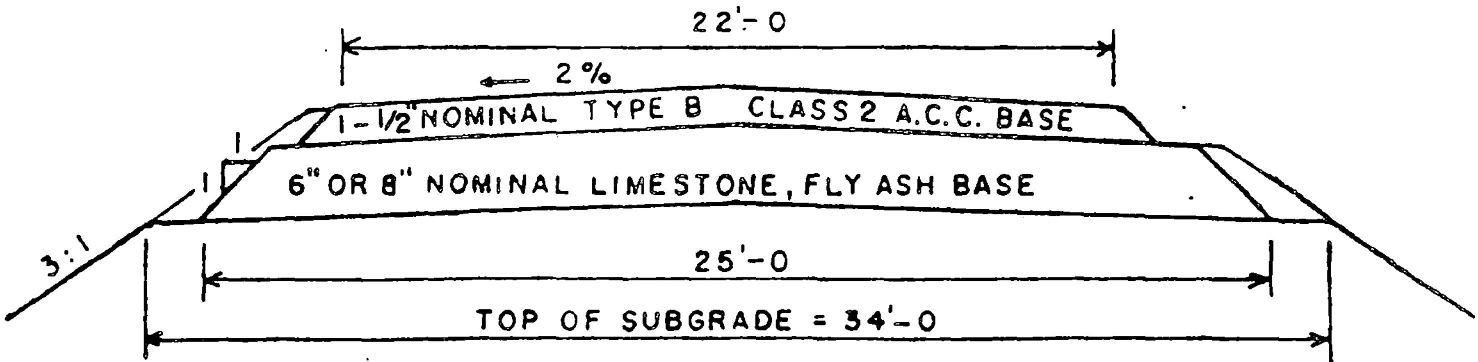
Figure 1. Project location.

Table 1. Placement Tabulation.

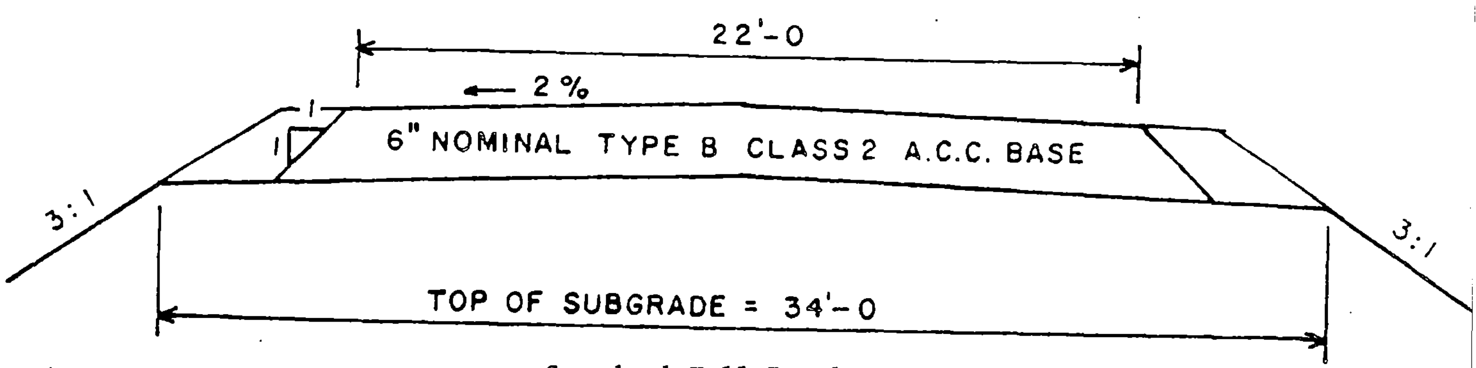
Sta. to Sta.		Depth	Lifts	Material
		Wearing Course		
101+00	152+18	1.5"	1	Type B Base
989+00	1007+00	1.5"	1	Type B Base
1007+00	1030+50	3/8"	Cover Agg.	Bituminous Seal Coat
		Base Course		
101+00	107+00	4.5"	2	Type B Base
107+00	110+00	4.5"–6"	1	Type B Base
110+00	119+00	6"	1	Mix No. 1 Fly Ash Base
119+00	123+00	6"–8"	1	Mix No. 1 Fly Ash Base
123+00	130+00	8"	1	Mix No. 1 Fly Ash Base
130+00	132+00	8"–7.1"	1	Mix No. 1 Fly Ash Base
132+00	138+00	7.1"–4.5"	2	Type B Base
138+00	152+18	4.5"	2	Type B Base
989+00	1007+00	4.5"	2	Type B Base
1007+00	1011+00	6"–8"	1	Mix No. 3 Fly Ash Base
1011+00	1021+00	8"	1	Mix No. 3 Fly Ash Base
1021+00	1025+00	8"–6"	1	Mix No. 3 Fly Ash Base
1025+00	1030+50	6"	1	Mix No. 3 Fly Ash Base



Section 1 & 2



Section 3 & 4



Standard Full Depth

Figure 2. Typical cross sections of fly ash and ACC bases.

Section	Length	Description
1	1100	Seal coat + 6"(crusher fines, sand, and fly ash)
2	1100	Seal coat + 8"(crusher fines, sand,and fly ash)
3	1800	1.5" AC Surface+8"(crusher fines and fly ash)
4	550	1.5" AC Surface + 6"(crusher fines and fly ash)

Pavement sections are shown in Figure 2; placement tabulations are shown in Table 1. Section 1 represents a "standard" based on existing design methods. Sections 2 and 3 may represent "over-designs". Section 4 is a "high risk" section, the length of which has been minimized. Full-depth asphalt sections serve as a comparison to the test sections.

Tentative mix designs were conservatively established at 30 percent fly ash treated with 1.5 percent dibasic ammonium phosphate (18-46-0). Consideration was given to using Peterson pit sand alone, but experience in Des Moines County (HR-259) suggested that limited quantities of angular crushed limestone should be included to provide stability for compaction equipment [4]. Therefore, two tentative aggregate compositions were specified: (1) 3/8-inch crusher fines only (i.e., 100% crusher fines); and (2) 35% crusher fines mixed with 65% sand (i.e., crusher fines/sand mixture).

PRE CONSTRUCTION LABORATORY TESTS

Laboratory tests were performed to see how ammonium phosphate behaved with combinations of Ames fly ash, limestone crusher fines, Peterson pit sand and Hallet fill sand. Objectives were to establish construction criteria for compaction, strength, and set time, and also to evaluate freeze-thaw and wet-dry characteristics. Proctor test specimens were made at 20% and 30% fly ash contents by weight of aggregate. The essential physical characteristics of the aggregate are reported in Table 2; details of mix proportions are reported in Table 3.

Moisture-density - A typical result of a standard Proctor moisture-density test (ASTM D698-80) is shown in Figure 3; a summary of such tests for the trial mixtures is reported in Table 4. These data indicate the amount of fly ash and the type of aggregate used had little effect on maximum dry density and only a slight influence on optimum moisture content (OMC).

Compressive strength - The compressive strengths reported in Table 5 were determined both at OMC and at water levels of one to two percent above OMC. Fly ash content was found to be a significant factor affecting strength. For example, the base strength of the untreated aggregate was less than 17 psi and probably reflects either the apparent cohesion resulting from the surface tension of water, or the small amounts of clay present in the unprocessed sand. When 20 and 30 percent fly ash contents were added to the crusher fines, average strengths of 679 and 844 psi, respectively, were obtained.

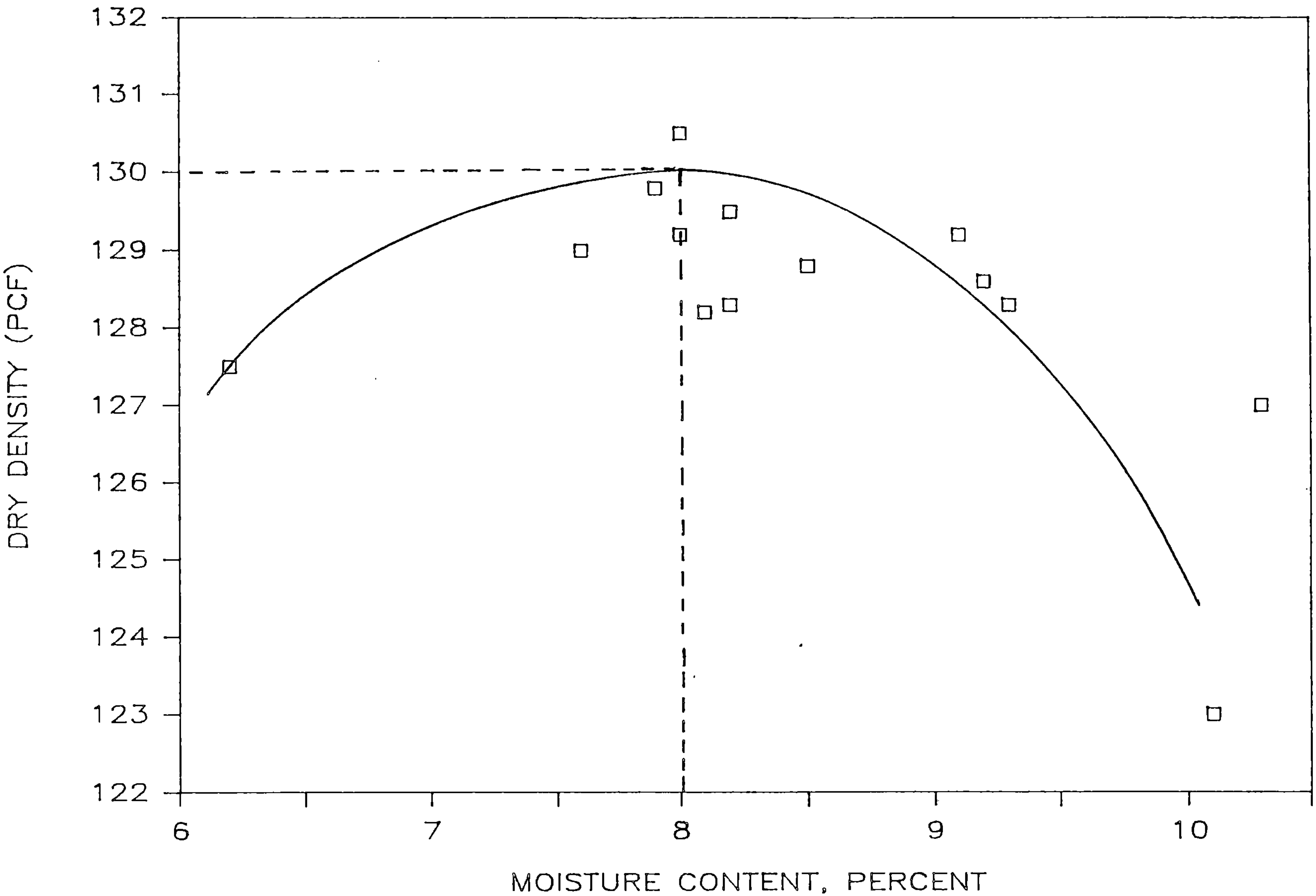


Figure 3. Moisture content vs. dry density, Mix No. 4.

Table 2. Aggregate Description.

(a) Limestone

Seive	% Retained
3/8"	0.57
3/16"	26.52
#8	25.23
16	17.00
30	7.24
50	8.79
100	9.87
100⁻	4.78
Total	100.00

(b) Peterson Pit Sand

Seive	% Retained
3/8"	0.00
#4	0.00
10	0.20
20	5.10
40	55.80
60	27.40
100	8.70
200	1.00
200⁻	1.80
Total	100.00

(c) Hallet Fill Sand

Seive	% Retained
3/8"	0.00
#4	0.00
10	23.30
20	25.90
40	28.90
60	16.70
100	4.60
200	0.40
200⁻	0.20
Total	100.00

Table 3. Design Mixes.

Mix #	Limestone	Peterson Pit Sand (%)	Ames Fly Ash (%)	Ammonium Phosphate (%)
1	100	---	20	1.5
2	100	---	30	1.5
3	35	65	20	1.5
4	35	65	30	1.5

Table 4. Compaction Characteristics of Mixes.

Mix #	OMC (%)	Max. Dry Density (lb/ft^3)
1	9.1	127
2	10.0	127
3	9.0	129
4	8.0	130

Average blends involving sand produced less strength (353 and 568 psi) at corresponding fly ash contents. Moisture levels slightly in excess of OMC caused a sacrifice of about one-third strength, an observation consistent with findings in HR-260 (where the strength of ammonium phosphate-fly ash cement was found to be dependent on water/cement ratio).

Frost resistance - A base of laboratory data was required to allow correlation with observed field freeze-thaw performance; the laboratory work was conducted by molding duplicate sets of standard Proctor specimens at OMC, then moist curing them for seven days. Following the moist cure, the specimens were subjected to twelve freeze-thaw cycles (per ASTM test standard D 560-82).* Upon thawing, one of the two sets of specimens is brushed and the amount of material lost is used as a measure of deterioration. Specimen dimensions then are taken from the second set to provide a measure of volumetric stability. At the conclusion of the test compressive strength is measured. Data resulting from these tests are presented in Table 6.**

ASTM C 593 criteria require a minimum of 400 psi compressive strength after freeze-thaw to constitute acceptable freeze-thaw

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* ASTM D 560-82 requires that duplicate specimens be frozen at -10 degrees F for 24 hours, then thawed in a humidity room at 70 degrees for 23 hours.

** It should be noted that tests on specimens employing fly ash only (i.e., no ammonium phosphate) were attempted but such "fly ash only" specimens disintegrated during the first freeze-thaw cycle.

Table 5. Strength Characteristics of Design Mixes.

Mix #	Moisture Content (%)	Dry Density (lb/ft^3)	7-Day Strength (psi)
1*	9.1	126.3	679
1**	10.5	127.2	384
2*	10.0	126.2	844
2**	11.4	126.6	351
3*	9.0	128.4	353
3**	10.2	126.4	244
4*	8.0	129.8	568
4**	9.5	128.3	440

Note: * Optimum Moisture Content.
** 1-2% above Optimum Moisture Content.

Table 6. Freeze-Thaw Tests.

Mix #	Maximum Volume Change (%) (Expansion)	Soil Loss (%)	7-Day Strength (psi)
1	3.62	8.30	445
2	4.79	4.05	663
3	1.14	13.16	402
4	1.49	7.63	755

Note: Strength obtained at thawed condition.
Volume change measured at frozen condition.

Table 7. Wet-Dry Tests.

Mix #	Maximum Volume Change (%) (Shrinkage)	Soil Loss (%)	7-Day Strength (psi)
1	2.16	6.04	926
2	3.56	2.33	1034
3	1.42	28.69	822
4	1.42	11.42	1585

Note: Strength obtained at oven dry condition.
Volume change measured at oven dry condition.

performance of portland cement and lime fly ash stabilized base courses. The Portland Cement Association criteria and AASHTO standards T 135-70 for freeze-thaw performance are based on weight loss limitations of 7 to 14 percent [5]. On the basis of these standards, the data shown in Table 6 suggest all of the mixes to be adequate.

Wetting-and-drying - ASTM standard D 559-82 can be used to evaluate environmental durability. This test is similar to freeze-thaw, except that the specimens are submerged in water for five hours, then oven-dried for 42 hours at a temperature of 160 degrees F. Weight loss and shrinkage are reported after 12 cycles, with acceptable losses of no more than 7 to 14 percent by weight. Data reported in Table 7 indicate that all mixes except mix No. 3 were adequate. The failure of mix No. 3 may result from sand, low fly ash content, or both in combination. Strengths after high temperature curing were observed to be higher, and it has been proposed that these accelerated cure strengths are representative of 28-day low temperature cure strengths.

Mold Time and Strength - The elapsed time between mixing and molding significantly affects strength, as shown by the strength data following 7-days moist curing, Table 8. Therefore, the transit time between the batch plant and the construction site is important. The mixes described in Table 8 were were molded at 0, 15, 30, 45, and 60 minutes after mixing; casual inspection of the table indicates strength decreases with time.

Table 8. Effect of Mold Time on Strength.

Mix #	Mold Time (min)	7-Day Compressive Strength (psi)
1	0	814
	15	759
	30	677
	45	534
	60	430
2	0	855
	15	792
	30	537
	45	465
	60	382
3	0	717
	15	566
	30	367
	45	243
	60	146
4	0	1021
	15	888
	30	602
	45	322
	60	235

Note: 8% Moisture Content (by weight of mix) and 0.5% Ammonium Phosphate was used.

SUBGRADE

The subgrade was compacted and graded to a two percent crown during the period August 11 - 15, 1986, in accordance with Iowa DOT standard specification 2109.04. Several types of tests were conducted to characterize the subgrade, as outlined below.

In-Situ Moisture-Density - Measurements were taken with a Campbell-Pacific nuclear moisture-density gage a few days after subgrade preparation. These moisture-density results (Table 9) indicate surface density to have been lower than that of the underlying soil. Measured moisture contents for the East-West sections were higher than those for the North-South sections, probably owing to evaporation after a rainfall (8/13/86). The East-West sections were tested three days after the rainfall (i.e., on 8/16/86) while the North-South sections were tested six days afterward (i.e., on 8/19/86).

Benkelman Beam Tests - Table 9 presents in-situ Benkelman beam data for both the East-West and North-South sections. The data for each section include an average maximum deformation (tire contact pressure, 75 psi), a deformation modulus (computed from the maximum deformation by Burmister's equation [5]), and a residual deformation upon unloading. From these results it can be seen that subgrade quality for the North-South section is better than East-West sections, a finding which agrees with the higher densities measured for the North-South sections.

Table 9. Moisture Content and Density Data of Subgrade.

Date	Depth inch	Station 1015+50 %MC	DD	East-West Station 1019+00 %MC	DD	Station 1026+00 %MC	DD	Station 1029+75 %MC	DD
8/16/86	Surface	12.6	120	11.6	103	10.9	111	12.6	109
	2	12.3	121	10.6	112	10.3	118	12.1	109
	4	14.1	118	10.2	116	10.2	124	11.4	120
	6	12.9	123	9.8	121	9.8	127	11.5	122
	8	12.3	124	9.6	122	9.4	129	11.6	121
	10	--	--	9.7	122	9.4	130	11.3	121
	12	--	--	9.5	125	--	--	11.6	120

Date	Depth inch	Station 127+00 %MC	DD	North-South Station 115+00 %MC	DD
8/19/86	Surface	6.9	112	8.4	116
	2	6.8	128	7.6	128
	4	5.8	130	7.2	130
	6	6.4	135	7.2	133
	8	6.0	135	7.2	130
	10	6.1	137	7.5	128
	12	--	--	7.3	127

NOTE:
%MC - Percent Moisture Content.
DD - Dry Density, pcf

Table 10. Benkelman Beam Test Results.

Date	Station	Maximum Deformation at 75 psi, inch	Deformation Modulus E, psi	Residual Deformation inch
		East-West		
8/16/86	1015+25	0.070	9000	0.006
	1018+00	0.034	18529	0.006
	1029+00	0.098	6428	0.001
	1030+25	0.044	14318	0.022
		North-South		
8/19/86	114+75E	0.034	18529	0.000
	115+00E	0.020	31500	0.002
	115+50W	0.012	52500	0.000
	126+75E	0.016	39375	0.000
	127+00E	0.014	45000	0.002
	127+25W	0.016	39375	0.000

Plate Load Tests - Table 11 presents the results of in-situ plate bearing tests performed on both North-South and East-West sections.

Table 11. Plate Load Test Results.

Date	Station	Modulus of Subgrade Reaction, pci	Permanent Deformation inch
East-West Sections			
8/16/86	1015+00	667	0.087
	1029+00	769	--
North-South Sections			
8/19/86	115+00	1538	0.015
	126+50	2380	0.026

Moduli of subgrade reaction were computed as per ASTM D 1195. As with the Benkelman beam test, these data indicate that the North-South sections are better than the East-West sections. Comparison of results from these sections to upper limit values of 300 pci reported in the literature [5] suggests that all the test sections have high load carrying capacities.

FLY ASH BASE CONSTRUCTION

Contract - The fly ash base was mixed and placed by Manatt's Incorporated of Brooklyn, Iowa, a subcontractor to the Des Moines Asphalt & Paving Company. Des Moines Asphalt & Paving Company provided the Type B, Class 2 asphalt cement concrete used in both full depth sections and as a surface on the experimental base. Copies of the contract and the special provisions are presented in Appendix A.

Equipment - A continuous stationary mixer with such supporting equipment as hoppers, gated belt feeders, water metering equipment, and a fly ash storage silo was located at the Manatt yard, about four miles southwest of the project. This plant had seen previous service for fly ash-portland cement base stabilization; therefore, the only modification for this job was a 6,000 gallon water tanker where the ammonium phosphate and part of the mix water were combined. A pump was used to recirculate and agitate the mixture, and also to deliver the mixture to the mixer.

Placement - The mix was delivered to the job in dump trucks and placed with asphalt pavers. Both half and full width pavers were used. Compaction was accomplished with a double drum vibratory roller. The surface then was sealed with 0.4 gal/sy of MC-70 or CSS-1. Contraction joints skewed 6:1 from the perpendicular were sawed to one-fourth the base thickness at 15 to 20 foot intervals.

Base composition - Mix numbers 1 and 3 (Table 3) were selected to be used on the North-South and East-West test sections respectively. Batch quantities per ton of base material are as follows:

Limestone Base
(Mix No. 1)

Material	Dry Weight (lb)
3/8" minus limestone	1517
Fly Ash	303
Ammonium Phosphate	4.5/ton of solids
Water	180

Sand and Limestone Base
(Mix No. 3)

Material	Dry Weight (lb)
3/8" minus limestone	582
Sand	1106
Fly Ash	303
Ammonium Phosphate	4.5/ton of solids
Water	180

Chronology - The plant was calibrated on 8-14-86 and 8-15-86. Construction began on 8-18-86. The following is a record of events pertaining to the project:

East-West Sections

8-18-86 --

Mixing began at the plant at 8:00 AM; the first loads arrived on site at 8:40 AM.

The mixture was quite workable and looked good behind the laydown machine. Rolling presented problems. The roller produced tension cracks and waves which could not be removed before the base set.

Proctor densities of ninety-five percent or greater of the maximum were easily achieved. Variations in the rolling pattern were attempted to provide a better surface, as was rolling both with and without vibration. The best results were obtained when the mix was allowed to set for about 25 minutes, or until it was firm under foot prior to the commencement of rolling. This caused some loss in density. One-half width laydown machine was used.

A CSS-1 seal bitumen was applied at approximately 0.4 gal/sy, but, because of the poor spraying pattern, it was necessary to apply this in two coats and the seal was not good.

The day's production was 970.3 tons of base material on 870 feet of road. The design for this amount of mix requires 3937 lbs of ammonium phosphate; a check on weights indicated 3973 lbs were delivered to the mix tank.

8-19-86 --

Excessive set retardation (more than two hours) was observed during the early part of the day. To improve the surface, a compaction technique was attempted which involved vibratory compaction soon after the mix could support the roller, followed by surface trimming with a motor grader, and static steel wheel compaction. Also, a roller was used as soon as the base was stiff enough to support it.

This approach provided an improved finish, but was ineffective in some cases because the mix was too hard to be trimmed by the grader. Densities measured after use of this method were 100% of the maximum. The last two loads of the day set up in the trucks and could be unloaded only with a front end loader.

The length of base constructed was 580 feet (stations 1016+00 to 1021+80); 713 tons of mix were used.

8-20-86 --

A very unproductive day: Only 178 tons (130 feet) of base was constructed (stations 1016+00 to 1014+70). In the early part of the day excessive set retardation (more than 90 minutes) was observed between stations 1015+00 and 1015+40. Quick setting made later construction impossible. Part of the problem is believed due to the low moisture content of the mix. Attempted to use 2 half-width laydown machines.

North-South Sections

<u>8-21-86</u> --

As the stockpile of sand depleted, the decision was made to produce and place Mix No. 3 (limestone) on the north-south sections.

The first loads arrived before the paver was ready, and consequently set problems were experienced. Also, it soon became evident that the mix was too harsh or sticky, indicating that the operation would be plagued by premature set.

The water-ammonium phosphate mixture was observed to be a different color than it had been on previous successful days, so samples of ammonium phosphate liquid from the tanker were collected for testing. Tanker problems were found: the agitation pipe was plugged and the tank was loaded with ammonium phosphate sediment.

To correct these problems, the tanker was emptied and the job shut down.

<u>8-22-86</u> <u>to</u> <u>9-2-86</u> --

This period was used to evaluate the problems and arrive at solutions allowing job completion. The following observations contributed to an assessment:

1. With the exception of the last two loads during the first two days of production (8/18/86 & 8/19/86), premature set was not a problem.

2. Inspection of the ammonium phosphate concentrate in the tanker at start-up on the third day (8/20/86) revealed clear fluid. The ammonium phosphate concentrate looked milky brown on the first day.

3. The ammonia concentration, an indication of the amount of ammonium phosphate in the mix, was more intense on the first and second days than on the third and fourth.

4. Moisture contents on the third day of production were 1-2 percent lower than desired. On the fourth day (8/21/86), moisture contents were held at desired level but premature set was still a problem.

5. The fourth day of production utilized limestone screenings only; these proved difficult to work and the mix bridged and

would not pass through the paver.

6. The first few loads did not set prematurely, even on problem days.

7. Hydrometer measurements reflecting ammonium phosphate concentration in the tanker indicate:

Date	Time	Percent of Design Concentration
8/20	10:00 AM	148%
8/21	8:30 AM	60%
8/21	10:30 AM	48%

8. After the ammonium phosphate concentrate tank was drained, a significant amount of ammonium phosphate sediment was present.

Possible causes for the problems noted above are as follows:

1. The ammonium phosphate concentrate became too dilute as production proceded. Thus the desired degree of retardation was more than adequate early in the day and later became inadequate as as suggested by hydrometer measurements.

2. A more reactive fly ash was encountered during construction. Laboratory tests with fly ash samples taken from the plant indicate no difference in behavior than that observed with samples used for preliminary design, however.

3. The water content was too low. Laboratory work suggested this could contribute to the problem. Day four construction suggested the appropriate amount of water helps but not enough.

4. Ammonium phosphate may not retard enough, particularly in large masses where hydration temperatures are significant. No data available to support or discredit this contention. Logic indicates hydration temperature can be a factor.

5. Particle shape and gradation of limestone screenings alone do not allow for a workable mix.

Based on the above information it was decided (1) that the mix would be modified by using sand and ammonium lignosulfonate, per Table 12;

Table 12. Modified Mix No.3.

Aggregate (dry weight)	Limestone	1225 lb.
	Sand	305
Fly Ash		305
Water (9% by weight of solids)		165
		2000 lb.

Note: Ammonium Lignosulfonate 1% by weight of fly ash.

Table 13. Ammonium Lignosulfonate and Compressive Strength.

Lignin Concentration (% by weight of fly ash)	24-Hour Compressive Strength (psi)	
	PPS	HFS
0.0	580	700
0.5	530	590
1.0	440	485
1.5	410	400
2.0	370	290

Note: Lignin - Ammonium Lignosulfonate.
PPS - Peterson pit sand.
HFS - Hallet Fill sand.

and (2) that the ammonium phosphate would be placed in suspension by the fertilizer supplier and delivered in liquid form, after which active air agitation would take place, rather than fluid recirculation. It has been demonstrated that ammonium liognosulfonate has potential of retarding fly ash set. However, Table 13 suggests that strength may be sacrificed.

Construction resumed on 9-11-86. The following is a record of events pertaining to the project:

<u>9-11-86</u> --

Paving started at station 129+08 and tapered over the previously laid base. At station 128+80, full depth new placement began with a full width paver.

The mix worked extremely well and no early setting was observed; however, some soft spots appeared between stations 127+60 and 128+00.

Due to several mechanical problems at the mixing plant and the construction site, progress was rather limited and only 208 feet were placed (from station 129+08 to station 127+00).

<u>9-12-86</u> --

This was the best working day of the project: About 1215 feet were paved (from station 127+00 to station 114+85); also, the mixes looked fine and compacted up to 1-2 inches. A 150 feet long section (from station 124+50 to station 123+00) was laid without roller compaction because it gave a better surface finish at the cost of lower density (89% of maximum dry density).

On the whole the operation was smooth. Most important, no setting problem was observed even though some localized soft spots were noted.

CSS-1 sealer was applied from station 127+00 to station 118+00; MC70 sealer was applied from station 118+00 to station 114+00.

9-13-86 --

This was the last day of fly ash base construction; 591 feet of the base (from station 114+86 to 109+95) were constructed. Paving went smoothly, resulting in good compaction and surface finishes before the application of sealer. Pavement thickness varied throughout the section, ranging from 7-8 1/2 inches; width was 24 1/2 feet.

QUALITY CONTROL

The "in place" water content of the limestone crusher fines and sand stocks were continuously measured by a "Speedy Moisture Tester" to maintain optimum water content because the strength of fly ash base is extremely sensitive to water content. The Speedy Moisture Tester gave a lower moisture content (1%) than the gravimetric method, which factor was was taken into account when adjusting the final water content of the base mix. This final water content was again measured by the Speedy Moisture Tester.

Laboratory Tests

Base samples were collected from the batch plant during mixing and transported to Spangler Geotechnical Laboratory where two inch diameter x two inch high cylinders were molded. About 30 minutes of time elapsed between mixing at the plant and molding at the laboratory.

Test results on samples from the East-West and North-South sections are as follows:

East-West Sections --

Laboratory test results are presented in Table 14. On comparing these results with the results reported in Table 5, it can be seen that the maximum 7 day strength of 428 psi obtained 8/18/86 was higher than 7 day strength of Mix No. 3 samples mixed and molded in the laboratory (353 psi).

North-South Sections --

Results are presented in Table 15. On comparing these results with those reported in Table 5, it can be seen that higher strength (1014 psi) was obtained for the plant mix than the laboratory mix (679 psi, Mix No.1).

Table 14. Laboratory Strength of Fly Ash Concrete Made from Plant Mix (Mix No.3), East-West Sections.

Date of Mixing	Time of Testing	Mix Water Content (%)	Strength (psi)
8/18/86	1 hr	7.78	154
	2 hr	7.99	221
	3 hr	7.98	275
	4 hr	8.22	354
	1 day	8.15	369
	7 day	8.24	428
8/19/86	1 hr	9.55	9
	2 hr	9.69	43
	3 hr	9.22	56
	4 hr	9.93	86
	1 day	9.93	117
	7 day	9.73	124
8/20/86	1 hr	6.72	370
	2 hr	6.81	370
	3 hr	6.90	343
	4 hr	6.82	316
	1 day	6.71	338
	7 day	6.99	318

Table 15. Laboratory Strength of Fly Ash Concrete Made from Plant Mix (Mix No.1), North-South Sections.

Date of Mixing	Time of Testing	Mix Water Content (%)	Strength (psi)
8/21/86	1 hr	10.01	62
	2 hr	10.13	85
	3 hr	10.16	123
	4 hr	9.84	377
	1 day	9.75	718
	7 day	9.72	1014

Table 16. Laboratory Strength of Fly Ash Concrete made from Plant Mix (Modified Mix No. 3), North-South Sections.

Date	Time	Compressive Strength (psi)
9-11-86	1 hr.	243
11-30 AM	2 hr.	304
	3 hr.	358
	4 hr.	329
	24 hr.	397
	7 day	571
9-12-86		
3-00 PM	1 hr.	333
	3 hr.	762
	5.5 hr.	831
	7 day	1173
	28 day	1157
9-13-86	4 hr.	720
9-45 AM	7 day	1023
	28 day	1169
9-13-86	4 hr.	790
10-45 AM	7 day	1263
	28 day	1342

Table 15 presents further test results for North-South sections. With the exception of 9-11-86 much higher strengths were obtained than the first attempt on this section. It is interesting that in about 3-4 hours strength reaches more than 50% of 28 day strength and 7 day strength was more than 85% of 28 day strength. This may indicate compaction properties of the modified mix were superior to those of earlier mixes.

Compaction Characteristics

As described in the "Construction" section, various procedures were followed for compaction of the base. In situ moisture content and dry density were continuously measured both before and after compaction with the nuclear gage mentioned in the subgrade section. Densities are expressed in actual and relative amounts, the latter representing the percent of maximum dry density of 130 pcf obtained from laboratory tests.

East-West Sections --

Pavement thickness before compaction was 6-8" (stations 1030+50 to 1022+80) with two inches of compaction for an anticipated design thickness of 6 inches.

Between stations 1022+00 and 1017+00, the the mix was laid at 8-10" with 0-2" of compaction.

Moisture content and dry density were continuously measured, with results presented in Table 17.

Compacted water contents of 7% and above generally gave good compaction. At water contents below 6% compaction was poorer.

The time lag between placing and rolling the base played an important role. Immediate rolling gave higher density, but only at the cost of surface finish. Waiting about 25 minutes improved the surface finish but lowered density (the base was getting too stiff to compact well). It was noted that increasing the vibration during paving (by slowing down paver movement) produced a strong base at station 1017+00.

Table 17. In Place Moisture Content and Dry Density of Fly AshConcrete (Mix No.3), East-West Sections.

Date	Station	Moisture Cont, % Uncom.	Moisture Cont, % Com.	Dry Density, pcf Uncom.	Dry Density, pcf Com.	Rel. Compaction Uncom.	Rel. Compaction Com
8/18/86	1030+00N	6.1	7.0	111	120	86	92
	1029+50N	8.0	7.0	118	123	89	95
	1029+50S	6.4	6.1	116	124	91	95
	1029+00N	5.5	5.7	114	119	88	92
	1029+00S	7.4	7.2	118	132	90	100
	1028+00N	-	7.2	-	131	-	100
	1028+00S	-	7.5	-	132	-	100
	1027+00N	7.2	7.2	119	125	92	96
	1027+00S	6.9	6.2	109	124	84	96
	1026+00N	-	6.9	-	116	-	89
	1026+00S	-	7.6	-	125	-	96
	1026+00M	-	7.3	-	117	-	90
	1025+00S	6.6	-	110	-	85	-
	1024+00N	8.1	6.7	120	124	92	96
	1024+00S	-	5.8	-	117	-	90
	1024+00M	-	5.9	-	118	-	91
	1023+00N	-	6.9	-	119	-	92
	1023+00S	-	9.3	-	129	-	99
	1022+00N	-	8.4	-	128	-	98
	1022+00S	-	8.0	-	125	-	96
8/19/86	1022+00N	8.3	7.8	124	129	95	100
	1022+00S	6.7	7.4	116	112	89	86
	1021+00N	9.0	8.0	116	132	89	100
	1021+00S	8.5	8.1	120	121	92	93
	1020+00N	6.8	6.3*	129	122*	99	94*
	1020+00S	9.0	6.9*	121	123*	93	95*
	1019+00N	-	5.7	-	123	-	94
	1019+00S	-	8.0	-	132	-	100
	1018+00N	-	7.5	-	130	-	100
	1018+00S	-	8.2	-	129	-	99
	1017+00N**	-	7.3	-	129	-	99
	1017+00S**	-	6.5	-	131	-	100

NOTE:

Measurements were from 6 inch depth unless noted.

* Measurements were from 4 inch depth.

** Paver slowed down and vibrated longer.

N, S, and M North, South, and Mid-section of the pavement.

Relative compaction based on the maximum dry density of 130 pcf obtained from laboratory tests.

North-South Sections --

Thickness and density measurements are presented in Tables 18 and 19, respectively.

Uncompacted thickness varied from station to station. For example, from station 129+08 to 128+80, a tapered section was applied over a previously laid base, where uncompacted thickness varied from 0-10". From station 128+80 to 122+00, uncompacted thickness varied from 9-11". From station 121+00 to 108+95 the uncompacted thickness was 8-9".

The amount of compaction varied with the time elapsed between placement and compaction, but compaction characteristics generally were much better than experienced in previous tests. In most cases, 2 inches of compaction was achieved, and practically no early setting problem was observed.

No compaction was done between stations 124+50 and 123+00 to allow evaluation of base directly from the paver. This length serves as a separate test section.

Scattered low densities observed early in the test between station 127+00 and 125+00 may indicate either mixing was improper at the beginning or segregation took place. However, good compaction and excellent density both were achieved later. This may be attributed to good mixing as well as compaction and indicates the modified mix design worked extremely well in increasing workability, set retardation, and compactibility.

Field Tests - Coring

Three inch diameter cores were taken in both the East-West and North-South sections of the project to evaluate the strength of the fly ash base. Cores were first tested within 15-22 days, and again after 7-8 months, during which time the base was exposed to one winter season.

Table 18. Construction Details of North-South Sections (Modified Mix No.3).

Unit #	From Sta.	To Sta.	Length	Begin Unit	End Unit	Time Compacted	Laydown Depth	Time Sealed	Comments
				9-11-86					
1	129+08	128+40	68'	10:03	10:32	10:36	0-10"	7:00	Taper 1029+08-1029+80 2"+ No Vibrating
2	128+40	127+83	57'	11:00	11:13	12:15	9-10"	7:00	Plant broke down wet loads
3	127+83	127+64	19'	1:50	1:56	3:00	10-11"	7:00	2 loads, fly ash plugged up
4	127+64	127+00	36'	5:00	5:17	6:45	9-10"	7:00	Rain started delayed rolling
				9-12-86					
1	127+00	126+35	65'	9:15	9:45	9:55	10-11"	2:00	1-2" Comp., East edge still soft.
2	126+35	125+50	85'	12:05	12:50	12:55	10"	2:00	1.5-2" Good 2-3" rollout
3	125+50	124+75	75'	12:55	1:14	1:20	10"	2:00	Coompacted almost immediately,2"+ compaction
4	124+75	124+50	25'	1:20	1:30	1:45	10"	4:10	Had set up, 1" compaction
5	124+50	123+00	150'	1:41	2:32	NONE	10"	4:10	No compaction test section
6	123+00	122+00	100'	2:35	3:10	3:25	9.5-10"	6:00	Average 1-2", Roller made big hole
7	122+00	121+00	100'	3:10	4:00	4:30	9"	6:00	1-2" compaction
8	121+00	120+00	100'	4:05	4:34	4:30	8.5-8"		Good compaction, 2"+
9	120+00	119+00	100'	4:35	5:10	5:15	8"		Good compaction, 2"+
10	119+00	118+00	100'	5:15	5:35	5:50	8"		1-2" compaction
11	118+00	117+00	100'	5:40	6:15	6:15	8"		Good
12	117+00	116+00	100'	6:15	6:45	6:45	8"		Good
13	116+00	114+85	115'	6:45	7:25	8:00	8"		Good taper
				9-13-86					
1	114+86	114+00	86'	8:15	8:46	9:00	9"		Tried rolling @ 8:50, too dry 1-1.5" compaction
2	114+00	113+70	80'	8:46	9:00	9:20	9"		Fair compaction, 2-3" rollout
3	113+70	113+00	70'	9:10	9:30	9:30	9"		Wetter mix, some cracking on rolling
4	113+00	112+00	100'	9:36	10:00	10:00	8"		Some low spots, good finish on compacting 1-2"
5	112+00	111+00	100'	10:00	10:35	10:35	9"		Good compaction, 2-3" rollout
6	111+00	110+00	100'	10:40	11:00	11:00	7-8"		Paver some troubles, Sta. 110+60 7" depth
7	110+00	108+95	105'	11:00	11:30	11:50	8"		1-1.5" compaction

Table 19. In Place Moisture Content and Dry Density of Fly Ash Concrete, North-South Sections.

Date	Station	Moisture Cont, %		Dry Density, pcf		Rel. Compaction	
		Uncom.	Com	Uncom.	Com.	Uncom.	Com.
9/11/86							
	128+50E	7.4	-	118	-	86	-
	128+50W	5.9	-	90	-	69	-
	127+50E	6.4	-	106	-	82	-
	127+50W	7.3	-	113	-	87	-
9/12/86							
	127+00E	6.8	8.2	118	119	91	92
	127+00W	7.3	8.5	113	129	87	99
	127+00M	-	8.3	-	126	-	97
	126+25E	7.4	7.3	115	113	88	87
	126+25W	7.2	7.8	114	129	88	99
	126+25M	-	6.6	-	118	-	91
	125+50E	-	6.5	-	132	-	100
	125+50W	-	6.1	-	124	-	95
	125+50M	-	6.6	-	124	-	95
	125+00E	-	6.9	-	119	-	92
	125+00W	-	7.1	-	121	-	93
	No compaction between Station 124+50 to 123+00						
	124+00E	7.0	-	122	-	94	-
	124+00W*	6.2	-	110	-	84	-
	123+50E*	6.1	-	126	-	97	-
	123+50W*	5.5	-	127	-	97	-
	123+00E*	7.0	11.8	111	?	85	?
	123+00W*	7.7	?	101	?	78	?
	122+50E	7.3*	6.7	107*	131	81*	100
	122+50W	7.3*	6.6	107*	130	82*	100
	122+00E	7.4*	7.4	125*	136	96*	100
	122+00W	-	7.3	-	131	-	100
	121+00E	-	7.5	-	134	-	100
	121+00W	-	7.4	-	134	-	100
	121+00M	-	7.5	-	132	-	100
	120+00E	-	8.7	-	133	-	100
	120+00W	-	8.5	-	132	-	100

Table 19 (Continued)

Date	Station	Moisture Cont, %		Dry Density, pcf		Rel. Compaction	
		Uncom.	Com	Uncom.	Com.	Uncom.	Com.
	119+00E	-	7.5	-	133	-	100
	119+00W	-	7.4	-	132	-	100
	118+00E	-	8.1	-	133	-	100
	118+00W	-	8.3	-	132	-	100
	117+00E	-	7.7	-	133	-	100
	117+00W	-	8.2	-	135	-	100
	116+00E	-	7.0	-	135	-	100
	116+00W	-	6.9	-	135	-	100
	115+00E	-	7.8	-	134	-	100
	115+00W	-	8.1	-	132	-	100
9/13/86							
	115+00E	-	5.0	-	120	-	92
	115+00W	-	4.7	-	127	-	97
	114+00E	-	5.4	-	129	-	99
	114+00W	-	5.2	-	129	-	99
	113+00E	-	6.8	-	135	-	100
	113+00W	-	7.3	-	141	-	100
	112+00E	-	6.0	-	135	-	100
	112+00W	-	5.8	-	126	-	97
	111+00E	-	6.9	-	138	-	100
	111+00W	-	6.8	-	136	-	100
	110+00E	-	6.2	-	137	-	100
	110+00W	-	6.1	-	136	-	100
	109+00E	-	8.2	-	137	-	100
	109+00W	-	8.2	-	138	-	100

NOTE :

Measurements were from 6 inch depth unless noted.

* Measurements from 10 inches depth.

? Values too low to obtain from Moisture and Density chart.

E, W and M East, West, and Middle of the pavement section.

Relative compaction based on the maximum dry density of 130 pcf obtained from laboratory tests.

East-West Sections --

Station 1007 to 1030+50.

Results are presented in Table 20 (a). Cores were taken from different locations, from stations 1018 to 1029. On the basis of visual inspection the base appeared to be a well compacted coherent mass and it was possible to obtain good cores, which indicated an average 15-16 day strength of 324 psi; one core from station 1029 showed a 244 days strength of 476 psi. In general, however, the base was not strong enough to withstand the disturbance caused by the drilling operation and core strengths were lower than those of North-South sections.

North-South Sections --

Station 109+95 to 129+08.

Results are presented in Table 20 (b). In general cores were easily obtained and looked very well cemented and coherent. However, cores obtained from the very early part of the paving (Station 127 E) and the uncompacted section (Station 124 E) were segregated and high void contents were visible; as a result 220 day strength was only around 200 psi. In general strength decreased with age. Average 15-16 day strength (834 psi) is higher than 218-220 day strength (530 psi). Typical lime-fly ash-aggregate mixtures have been reported as generally having strengths ranging from 500 to 1000 psi after about one year of service [4]. Average core strength falls within this range, indicating ammonium phosphate treated fly ash concrete is strong enough to act as base course.

Table 20: Core strength of fly ash base.

(a) East-West Sections

Station	Compressive Strength (psi) 15-16 days	Compressive Strength (psi) 243-244 days
1018	293	
1022	236	
1029	445	476
Average	324	476

(b) North-South Sections

Station	Compressive Strength (psi) 20-22 days	Compressive Strength (psi) 218-220 days
110W	1436	784
111W	1328	
113E	1336	
114W	538	
115W	406	454
116E	897	658
119E	792	659
121E	631	529
122W	840	767
124E	342	208
124+50E		335
125E	846	668
126W		560
127E		205
Average	854	530

ASPHALT CONCRETE

Type B, Class II asphalt concrete was used to overlay all of the experimental test sections. The original plan was to use a seal coat on the East-West sections. The weakness of the sand-limestone base rendered this practice questionable. Additional changes to the design were use of a leveling course on the undulating surface of the North-South sections and a profiler on the East-West sections. Thicknesses of asphaltic concrete measured from drilling are shown in Table 21 below.

Table 21. Thickness of Asphalt Concrete.

Station From	Station To	Asphalt Concrete Thickness(inch) 1st Lift	Asphalt Concrete Thickness(inch) 2nd Lift
North-South			
109+00	132+00	3	1-1/2
East-West			
1015+00	1021+80	1	1 1/2
1021+80	1030+50	1	1 1/2

STRUCTURAL TESTING

The Iowa DOT Road Rater was used to determine the structural rating of the research sections prior to asphalt overlaying. The structural rating from the Road Rater tests and corresponding base thickness, relative compaction, core strength and modulus of subgrade reaction are in Table 22. Base thickness was determined by drilling.

If it is assumed the structural rating can be equated to the AASHTO structural number, an estimate for structural layer coefficient for the experimental base material can be computed. These values are also given in Table 22. A linear relation with a 0.64 correlation coefficient in Figure 4 indicate structural layer coefficient is sensitive to compressive strength. The structural layer coefficients for the stronger fly ash bases are somewhat greater than the 0.44 limit previously assigned to such bases. In fact, values for the North-South sections are higher than those assigned to asphaltic concrete.

Figure 4 shows structural layer coefficient increases with unconfined compressive strength. Thus the layer coefficient may serve as a valuable indicator of the quality of a base.

Table 22. Road Rater Measurements on Road Base Materials.

Sta. to Sta.		Structural Rating	Base Thickness (inches)	Structural Layer Coeff.	Relative Density	Core Strength (psi)	Modulus of Subgrade Reaction K (pci)
North-South							
Fly Ash Base							
110+00	114+50	3.59 (0.63,10)*	7.5	0.48	99 (1,12)	1160 (417,4)	
115+00	122+50	3.42 (0.62,16)	7.2	0.48	100 (0,10)	713 (198,5)	1538
123+00	124+00**	3.13 (0.78,3)	7.2	0.43	89 (8,6)	342 (- ,1)	
125+00	128+50	4.02 (0.77,9)	7.5	0.54	95 (4,11)	846 (- ,1)	2380
East-West							
Fly Ash Base							
1015+00	1021+50	2.75 (0.66,11)	7.8	0.34	97 (3,10)	293 (- ,1)	667
1022+00	1030+50	1.95 (0.47,16)	8.3	0.23	95 (4,21)	445 (148,2)	769

NOTE : * Numbers in parentheses are standard deviation and number of tests respectively.

** Uncompacted section.

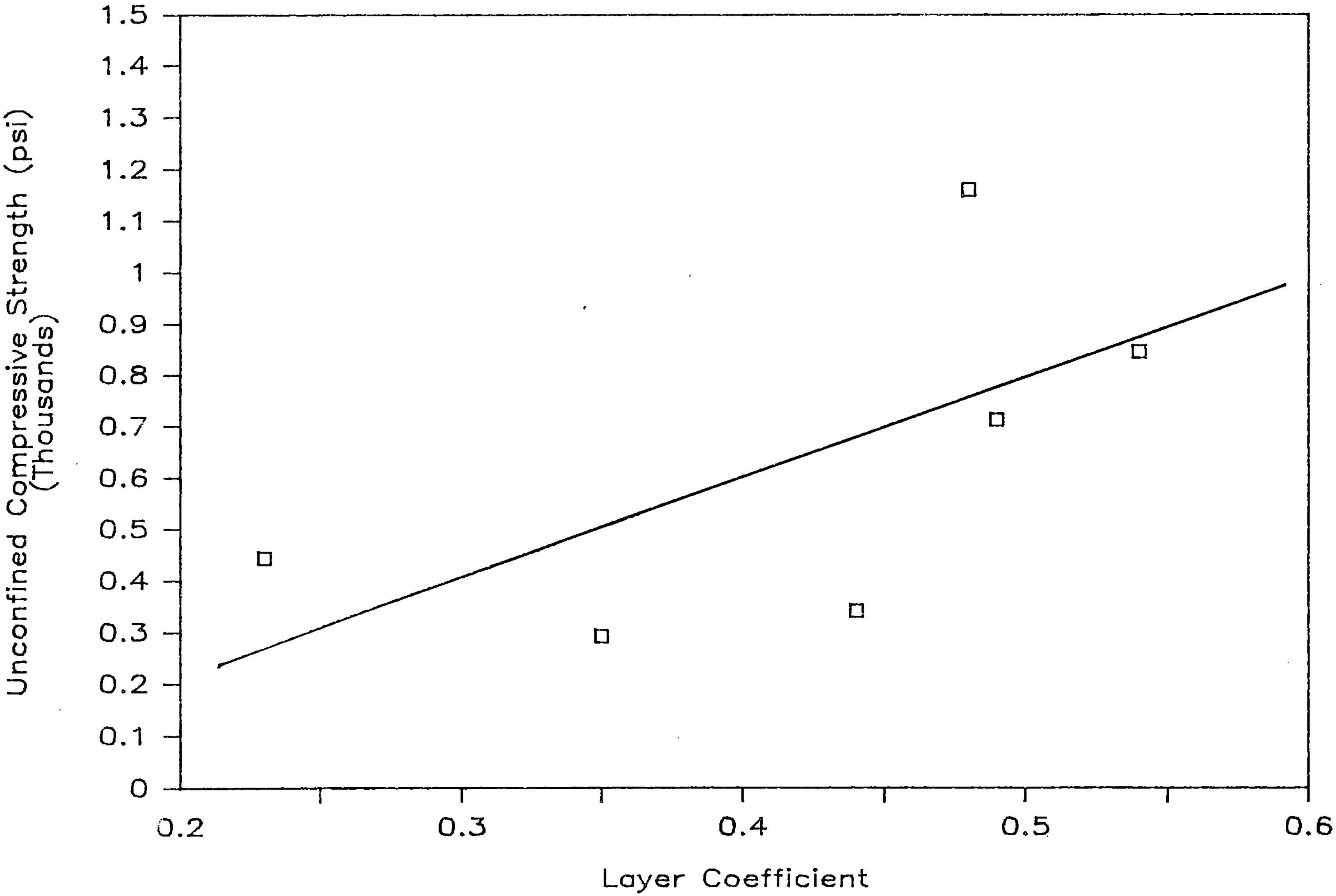


Figure 4. Structural layer coefficient and compressive strength.

LIGNOSULFONATE RESEARCH

The McFarland Park project demonstrates set time rather than strength characteristics may be the governing factor in fly ash stabilization. Because of inadequate mixing equipment, ammonium phosphate was not allowed to consistently retard fly ash set in our actual field conditions. Lignosulfonate was included as an alternative thus laboratory research on this material in combination with phosphates was done. The intent was to find more effective, more cost efficient retarder/strength enhancer combinations.

Test Procedures

Strength and set time were tested as described below:

Strength -- Unconfined compressive strength was selected as one indicator of additive effectiveness. Test specimens in this study were prepared using a water/fly ash ratio of 0.24 and 0.30. At these ratios the paste for Ames fly ash was a homogeneous plastic. Fly ash paste mixes were prepared in compliance with ASTM method C 109 and all chemicals (except rock phosphate) were dissolved or dispersed into a stable solution/dispersion with the mixture water. Rock phosphate was dry blended with fly ash prior to mixing with water.

When mixing was complete, cylindrical unconfined compression samples were cast in split mold assemblies 2 inches in diameter by 4.0 inches long, then rodded and clamped between lucite plates. Six replicas were cast for each test variable. When molded, specimens were cured in a humidity room at 70 degrees F for 24 hours, then removed from the molds and returned to the humidity room until testing.

Set Time -- Fly ash paste was cast in four inch diameter, three-fourths inch deep pans. A Soiltest pocket penetrometer (Model CL-700) was used as a rapid method of measuring rate of early strength gain and set properties. The procedure involved pushing the penetrometer into the paste every few minutes until its capacity (60 psi) was reached [3]. A detailed presentation of these results is presented in Appendix B and can be summarized as follows:

All chemicals used are fertilizer grade except monobasic calcium phosphate and tribasic calcium phosphate, which were reagent grade.

> Monobasic calcium phosphate and lignin (weight ratio = 1) -- decreased strength, increased set time.
>
> Tribasic calcium phosphate and lignin (weight ratio = 1) -- decreased strength, increased set times.
>
> Triple super phosphate (TSP) -- strength reduction up to 6% concentration, strength increase at 8% and above concentrations; maximum set times of 160 minutes at 4% concentration.
>
> Triple superphosphate (TSP) and urea (weight ratio = 2.5) -- decreased strength, increased set times.
>
> Triple super phosphate (TSP) and lignin (2% by weight of fly ash) -- strength reduction up to 6% concentration, increasing tendency afterwards; set times of 240 minutes at 2% concentration.
>
> Rock phosphate -- increased strength, but showed very quick setting.
>
> Rock phosphate and lignin (2% by weight of fly ash) -- strength increase at 2-6% concentration; significant retardation, 150 minutes or more, observed.

Ammonium polyphosphate (10-34-0, liquid) -- decreased strength; maximum set time of 120 minutes at 1 % concentration.

Ammonium polyphosphate (10-34-0, liquid) and lignin (1% by weight of fly ash) -- strength increases at 1-2% concentration; significant extension in set times, 240 minutes at 1 % concentration.

Ammonium phosphate (18-46-0) -- Increases strength significantly; maximum set times of only 40 minutes at 1% concentration, set time decreases dramatically at higher concentration.

Ammonium phosphate (18-46-0) and lignin (1% by weight of fly ash) -- strength increases significantly; maximum set times of 95 minutes at 1% concentration after which it decreases sharply.

Patterns emerging from this study indicate that TSP enhances strength and achieves considerable extension of set time. The only problem associated with its use is that one needs a higher concentration of TSP (8% +/-) to achieve strength increase. At lower concentrations (4%) it also gives a very long set time, 160 minutes, which might well be advantageous. The water/fly ash ratio should be 0.30 or greater. Below this figure it becomes difficult to handle the mix. When used in combination with lignin as an additive, TSP may provide an alternative to ammonium phosphate and it is also cheaper. Liquid ammonium polyphosphate (10-34-0) mixes easily with water and may also work as an effective additive, especially in combination with lignin. Rock phosphate also increases strength, but decreases set time drastically (an undesirable consequence considering that overfast set has been a continuing problem) and economically is not feasible. Ammonium phosphate increases strength significantly. Ammonium phosphate and lignin gave the best response from the standpoint of both strength and retardation.

CONCLUSIONS AND COSTS

Conclusions:

Based on the experience gained on this project the following conclusions are suggested:

1. The concept is workable and the end product appears to be able to provide a satisfactory base.

2. The plant used to mix the aggregate-fly ash mixture must have adequate means for controlling the mix ingredients to a close tolerance.

3. If dry ammonium phosphate is to be used to retard set the solution must hold the material in suspension. Air agitation is the manner believed to be most adequate. Use of liquid ammonium phosphate may lessen the suspension problem but the cost may be prohibitive.

4. The mixes used on this project may have been placed near uniformity with a slip form paver. Also, a full width paver should provide more satisfactory placement and a better surface.

5. The mixture must have enough sand included to make it handle properly.

Costs:

The final costs for the 1.771 mile was $315,862.78. or $178,352.78 per mile. This includes shouldering, erosion control and traffic control. Story County had estimated the comparable cost using full depth, 6", asphalt concrete pavement to be about $185,000. This cost estimate was based on $10.00/ton for Type B Class 2 base which was bid at $19.76 and Asphalt Cement at $205.00/ton which was bid at $150.00.

If costs cannot be reduced as additional experience is gained this type construction may only be economical when petroleum product costs are very high.

ACKNOWLEDGEMENTS

Research Project HR-294 was sponsored by the Iowa Highway Research Board and the Iowa Department of Transportation. Partial funding for this project was from the Secondary Road Research Fund in the amount of $80,175.00.

The authors wish to extend appreciation to the Story County Board of Supervisors and the Iowa DOT for their support in developing and conducting this project. We also want to thank Des Moines Asphalt & Paving Co. and Manatt's, Inc., for their cooperation during the project. The Story County inspection personnel also deserve special recognition for their extra effort put forth during this project.

REFERENCES

1. Pitt, J.M. et al. "Final Report: Chracterization of Fly Ash for Use in Concrete." Iowa Highway Research Board, Ames, Iowa, Project HR-225, September 1983.

2. Bergeson, K.L., J.M. Pitt, and T. Demirel. "Increasing Cementitious Properties of Class C Fly Ash." Transportation Research Record 998, Transportation Research Board, National Academy of Sciences, 1984.

3. Pitt, J.M. et al. "Final Report: Optimization of Soil Stabilization with Class C Fly Ash." Iowa Highway Research Board, Ames, Iowa, Project HR-260, January 1987.

4. Klassen, S.J. and Kevin Jones. "Construction Report: Low Cost Fly Ash - Sand Stabilized Roadway." Iowa Highway Research Board, Ames, Iowa, Project HR-259.

5. Yoder, E.J. and M.W. Witzak. Principles of Pavement Design. Second Edition, 1975, John Wiley & Sons, Inc., New York.

APPENDIX A

(Contract)

Form 740333 6-75 ACC Pavement

A-1

CONTRACT

Kind of Work w/Fly Ash Treated Base Miles 1.771

Project No. M-187, HR294 County Story

THIS AGREEMENT made and entered by and between Story County, Iowa, by its Board of Supervisors consisting of the following members: Fred L. Mathison, Donald E. Nelson and William G. Stucky

________________, party of the first part, and

Des Moines Asphalt & Paving Co. of Des Moines, Iowa, party of the second part.

WITNESSETH: That the party of the second part, for and in consideration of two hundred seventy one thousand five hundred twenty and 60/100 Dollars ($ 271,520.60) payable as set forth in the specifications constituting a part of this contract, hereby agrees to construct in accordance with the plans and specifications therefore, and in the locations designated in the notice to bidders, the various items of work as follows:

Item No.	Item	Quantity	Unit Price	Amount
1	Base, Type B, Class 2 Asphalt Cement Concrete	5,135 Tons	$ 19.76	$101,467.60
2	Asphalt Cement	325 Tons	$ 150.00	48,750.00
3	Sand, Load and Haul	1,100 Tons	$ 3.00	3,300.00
4	Limestone, 3/8"	2,100 Tons	$ 6.30	13,230.00
5	Fly Ash	1,350 Tons	$ 18.00	24,300.00
6	Ammonium Phosphate	10 Tons	$ 360.00	3,600.00
7	Base, Mix, Haul and Lay	5,050 Tons	$ 8.50	42,925.00
8	Primer or Sealer Bitumen	3,000 Gals.	$ 1.22	3,660.00
9	Binder Bitumen	2,000 Gals.	$ 1.15	2,300.00
10	Cover Aggregate, 3/8"	60 Tons	$ 25.73	1,543.80
11	Shoulder Construction, Earth	186.3 Stas.	$ 54.00	10,060.20
12	Seed, Fertilize and Mulch	2.2 Acres	$ 1,000.00	2,200.00
13	Traffic Control		Lump Sum	1,584.00
14	Samples		Lump Sum	500.00
15	Mobilization		Lump Sum	12,100.00
			TOTAL	$271,520.60

Said specifications and plans are hereby made a part of and the basis of this agreement, and a true copy of said plans and specifications are now on file in the office of the County Auditor under date of May 15, 19 86.

That in consideration of the foregoing, the party of the first part hereby agrees to pay to the party of the second part, promptly and according to the requirements of the specifications the amounts set forth, subject to the conditions as set forth in the specifications.

That it is mutually understood and agreed by the parties hereto that the notice to bidders, proposal, the specifications for Story County Project No. M-187, Story County, Iowa, the within contract, the contractor's bond, and the general and detailed plans are and constitute the basis of contract between the parties hereto.

That it is further understood and agreed by the parties of this contract that the above work shall be commenced on or before, and shall be completed on or before:

	Approx. or Specified Starting Date or Number of Working Days	Specified Completion Date or Number of Working Days
	30 Working Days	Sept. 19, 1986

That time is the essence of this contract and that said contract contains all of the terms and conditions agreed upon by the parties hereto.

It is further understood that the second party consents to the jurisdiction of the courts of Iowa to hear, determine and render judgement as to any controversy arising hereunder.

IN WITNESS WHEREOF the parties hereto have set their hands for the purposes herein expressed to this and three other instruments of like tenor, as of the ______ day of ______, 19__.

Approved:
IOWA DEPARTMENT OF TRANSPORTATION

[signature]
Contracts Engineer

Date JUL 01 1986

Story County, Iowa
Party of the first part

By [signature]
Chairman

DES MOINES ASPHALT & PAVING CO.

By [signature]

SP8586

STORY COUNTY, IOWA

SPECIAL PROVISION
for
FLY ASH TREATED BASE
Project M-187
Research Project HR 294
June 17, 1986

THE STANDARD SPECIFICATIONS OF THE IOWA DEPARTMENT OF TRANSPORTATION, SERIES OF 1984, SHALL APPLY TO THIS PROJECT EXCEPT AS AMENDED BY THE FOLLOWING ADDITIONS. THESE ARE SPECIAL PROVISIONS AND THEY SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

8586.01 GENERAL. This work consists of furnishing, mixing and placing a fly ash treated base, using a mixture of sand, crushed limestone, fly ash, ammonium phosphate and water. The mixture shall be prepared and placed according to the plans and this specification. Two thicknesses and a minimum of 2 different mixes are required.

This is a research project designed to provide important information concerning this type of base. The requirements of the plans and specifications may be modified to meet these research goals.

A conventional asphalt cement concrete base or seal coat is specified as a wearing course.

8586.02 MATERIALS. Sand for this base will be furnished by the County at no cost to the contractor. The contractor shall furnish all other materials. The materials shall be as follows:

A. Sand is to be a locally available sand. Preliminary tests show the following characteristics:

Sieve Size	% Passing
No. 4	100
No. 8	100
No. 16	99
No. 30	98
No. 50	77
No. 100	19
No. 200	2.4

The sand will be furnished by the County in its natural location at East Peterson Pit, at no cost to the contractor. The contractor shall load and haul the sand. Any material larger than 1 1/2" shall be removed from the sand.

B. Crushed Limestone - This is a locally available material commonly referred to as 3/8 minus. Preliminary tests show the following characteristics:

Sieve Size	% Passing
3/4"	100-90
1/2"	100-85
3/8"	95-80
#4	95-70
#8	75-40
#16	60-25
#30	50-20
#50	35-15
#100	25-10
#200	20-10

Any material larger than 1 1/2" shall be removed.

C. Fly ash shall be furnished by the contractor from sources approved by the engineer. Fly Ash shall be hydraulic, rapid setting, self cementing, such as that produced at currently approved, uncertified sources as follows:

Neal #4	Sioux City
Louisa	Grandview
Lansing	Lansing
Ames	Ames

D. Ammonmium Phosphate shall be Orthophosphate-Monohydrate (18-46-0) or Dia Ammonium Phosphate (18-46-0). The chemical composition shall be $(NH_4)_2\ HPO_4$. The Ammonium Phosphate must be dissolved in water and added to the mix by being blended with the mix water.

E. Water. Section 4102 shall apply.

F. Sealer Bitumen. Shall be MC70.

G. Final Mixture. The final mixture shall be a combination of the following approximate quantities of individual materials based on dry weights.

Mix #1 - Limestone Fly Ash Base
3/8" minus - 1538 lbs.
Fly Ash - 462 lbs.
Ammonium Phosphate - 2.31 lbs.
Water - 140 lbs.

Mix #2 - Sand-Limestone - Fly Ash Base
3/8" minus - 538 lbs.
Sand - 1000 lbs.
Fly Ash - 462 lbs.
Ammonium Phosphate - 2.31 lbs.
Water - 180 lbs.

The County reserves the right to alter these mix proportions based on field conditions. The amount of water used may be adjusted by the engineer.

8586.03 EQUIPMENT. Equipment to be used shall be as follows:

A. Proportioning and mixing shall be in a stationary plant. A conventional ACC plant as described in 2001.22, a conventional PCC plant as described in 2001.21 or another type of plant such as described in 2001.08 may be used subject to the approval of the Engineer. A stationary plant of another type will be considered for approval.

B. Placing Equipment shall be capable of placing the mixture to the full width and required thickness in one pass or be able to spread one-half the width and required thickness in one pass with the adjacent width being placed within one hour after the first pass is placed. Vibrating screeds and/or pan vibrators shall be available for use. If construction procedure leaves an exposed joint at centerline it shall be kept moist until the adjacent base is placed.

C. Compaction Equipment. Initial compaction shall be by a vibratory roller or compactor meeting requirements of 2001.05F. Based on field conditions, a tamping type roller meeting the requirements of 2001.05A may be required. Final compaction shall be by a steel- or rubber-tired roller meeting requirements of 2001.05B or C. If necessary, the weight of the compaction equipment will be adjusted in the field by the engineer.

D. Distributor. Article 2001.12 shall apply.

8586.04 SUBGRADE. The subgrade shall be prepared by the contractor in accord with 2109.04 and will not be measured for payment.

8586.05 CONSTRUCTION. The mixture shall be spread to the full width and full thickness in one operation or one-half width and full thickness with the remaining one-half width placed so the matching longitudinal joint will not be exposed for more than one hour. Any exposed longitudinal joint shall be kept moist. The thickness is to be varied as shown on the plans.

The mixture shall be compacted immediately after spreading. Compaction shall be to a target density of 100 percent of the density determined by compaction of samples of production mixture in a single, molded specimen in accord with AASHTO T 99, with a minimum density of 95 percent. The compaction and compaction procedure shall be based on maximum achievable compaction. An initial test section is contemplated. Compaction of the outside 1 foot may be minimized by the engineer and will not be subject to test. The engineer may modify or delete these compaction requirements. If a longitudinal joint is constructed compaction shall be carried out in such a manner as to not destroy the vertical or near vertical condition of the base at the longitudinal joint.

An application of water may be necessary to facilitate compaction. A moist surface condition shall be maintained until the sealer bitumen is applied.

8586.06 SEALER BITUMEN. The completed base surface and edges shall be sealed at the rate of 0.2 gallon per square yard. The sealer shall be applied immediately after compaction of a section of base is completed. This may be done without the operation of equipment on the base. If field conditions are satisfactory the distributor may be allowed on the completed base with the axle load or capacity limited by the engineer.

8586.07 JOINTS. Some joints shall be sawn. Only those areas designated on the plans are to be sawn. Sawing of transverse joints shall be in accord with 2301.26 and 2301.27, skewed 6:1 at 15' and 20' intervals.

8586.08 ACC BASE. The contractor shall furnish and place a Type B ACC base on the completed fly ash base in accord with the plans and requirements of Section 2303. Placement of the full thickness in one lift is contemplated with Class I compaction. The full depth ACC Base shall be placed in accord with Section 2303.

8586.09 LIMITATIONS. The road will be partially closed to traffic during construction. The area from Sta. 110 to Sta. 132 will be closed. The area from Sta. 1007 to Sta. 1030+50 will be closed but adjacent residents must be allowed limited access. The remainder of the project will be marked "ROAD CLOSED - LOCAL TRAFFIC ONLY". Adjacent residents must be allowed access.

Except for sawing, there shall be no traffic or equipment operated on the completed base from the time the base is 3 hours old until it is 21 days old except as authorized by the Engineer. Hauling units which operate on the completed fly ash treated base shall be tandem axle, dual wheeled units. Loading may be restricted based on the strength of the cured base.

8586.10 SHOULDERS. The earth shoulders will be constructed by the contractor after the wearing course is placed. Shoulder material is available in East Peterson Pit. The contractor shall load and haul the material.

8586.11 METHOD OF MEASUREMENT. The various items involved in the construction of the fly ash treated base shall be measured as follows:

A. Sand. The quantity of sand used in the mix shall be measured by the ton when delivered to the mixing site.

B. Limestone. The quantity of 3/8" minus used in the mix shall be measured by the ton when delivered to the mixing site.

C. Fly Ash. The quantity of fly ash used in the mix shall be measured in tons when delivered to the mixing site.

D. Ammonium Phosphate. The quantity of ammonium phosphate used in the mix shall be measured in dry tons of material when delivered to the mixing site.

E. Alternate for Sand, Limestone and Fly Ash. If a batch plant is used the weights of these materials may be computed by counting batches in each truck and batch weights.

F. Base; Mix, Haul and Lay. Article 2303.27A(1) shall apply.

8586.12 BASIS OF PAYMENT.

A. Sand, Limestone, Fly Ash, Ammonium Phosphate. For the number of tons of each measured for payment and used in the completed base the contractor will be paid the contract price per ton.

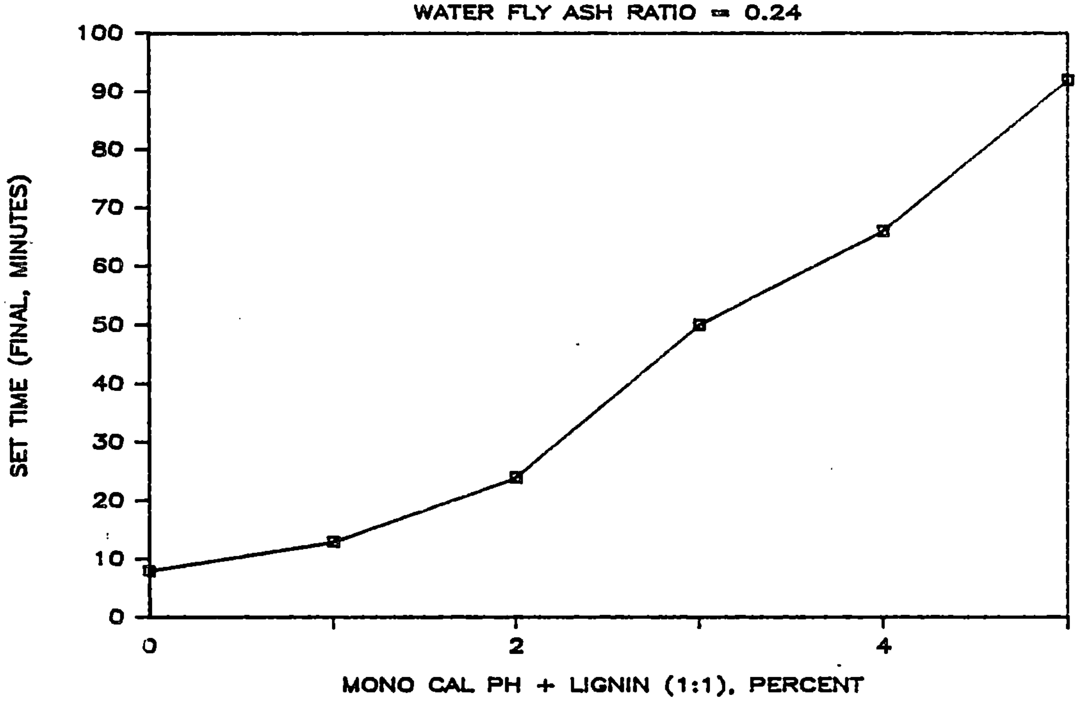
B. Base. Article 2303.28 shall apply.

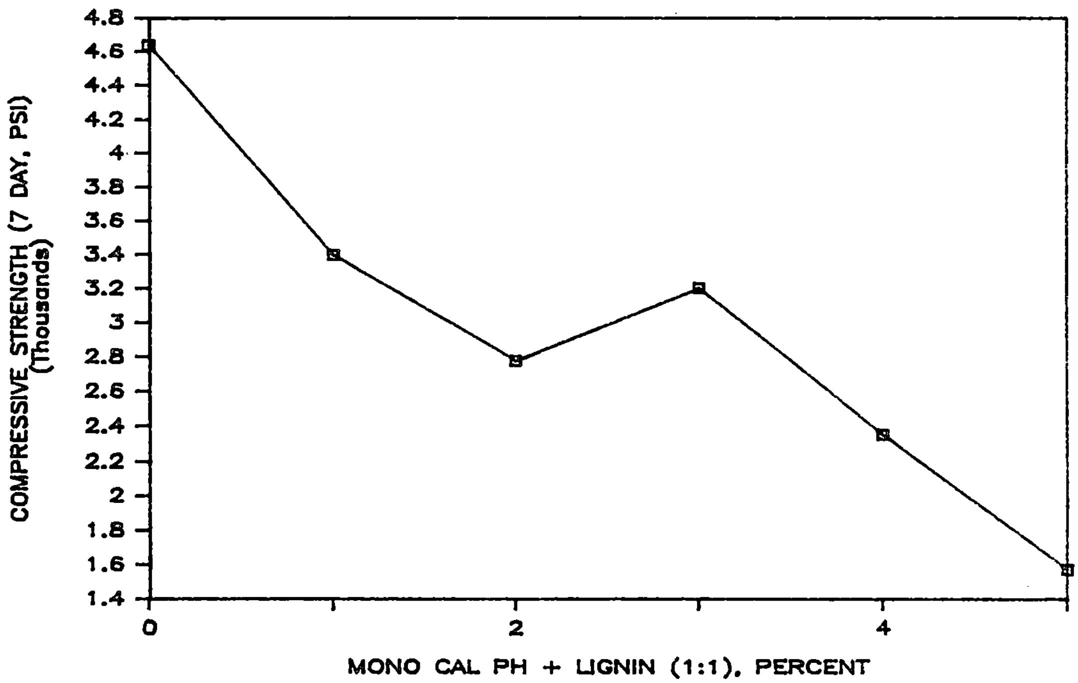
APPENDIX B

(Graphs)

AMES FLY ASH

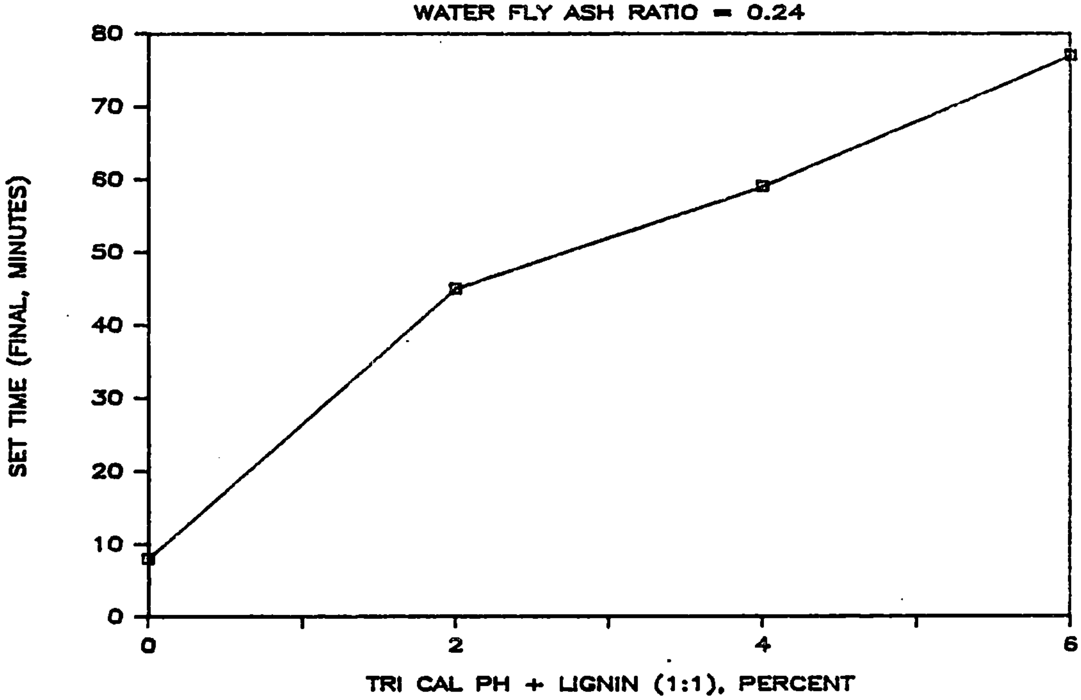
WATER FLY ASH RATIO = 0.24

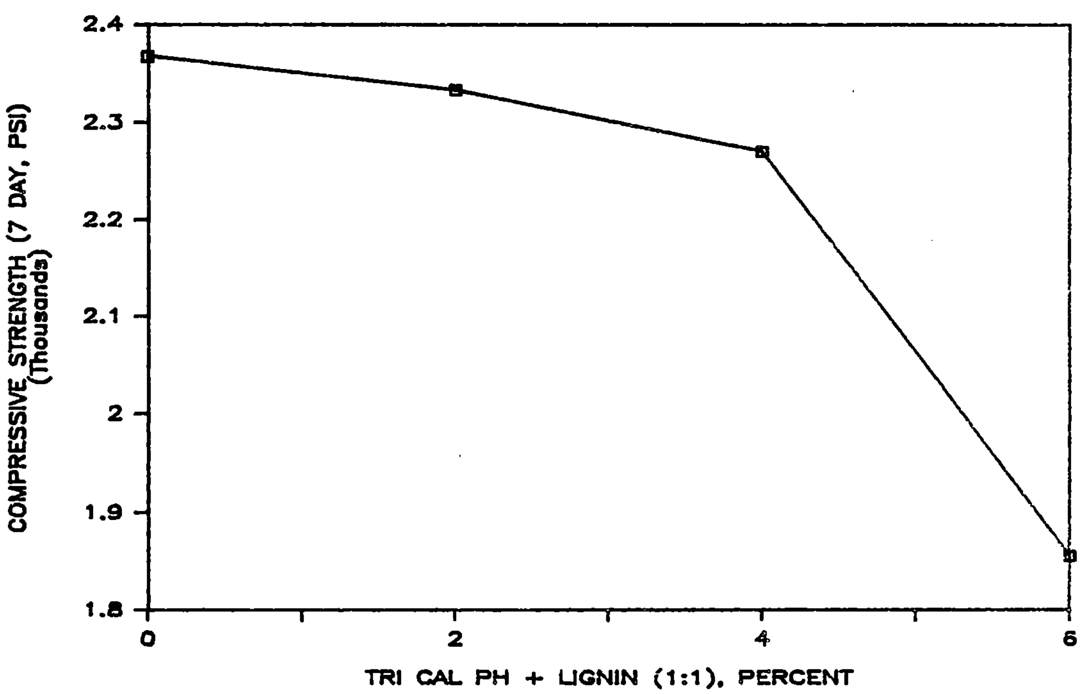


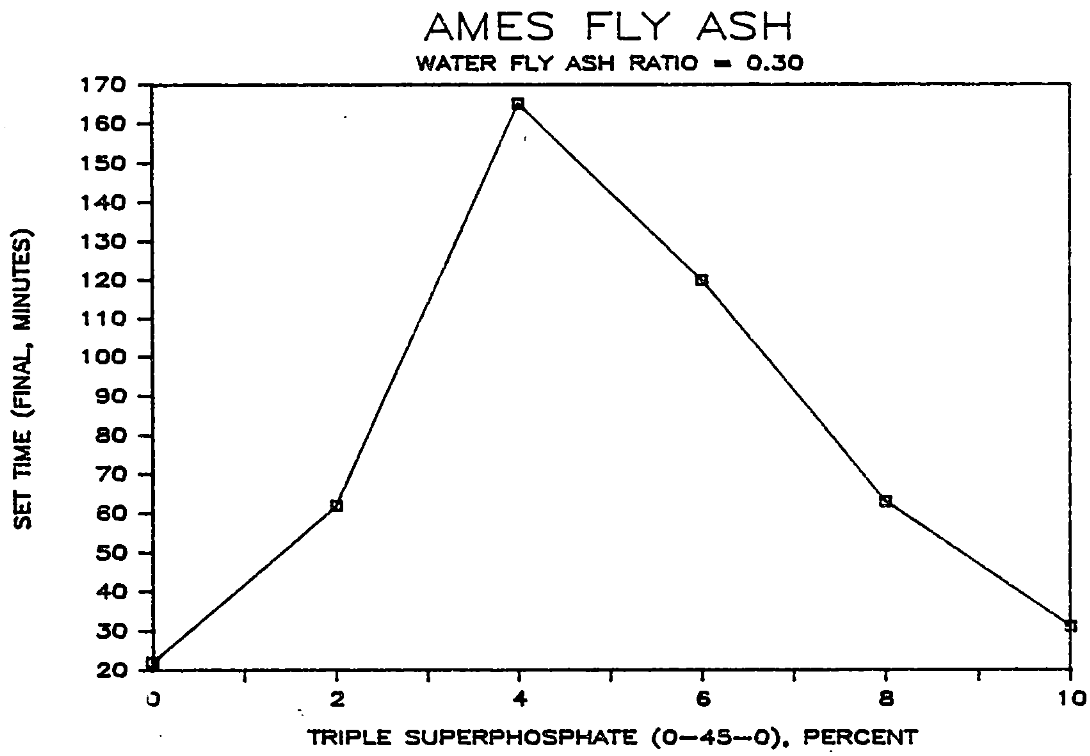


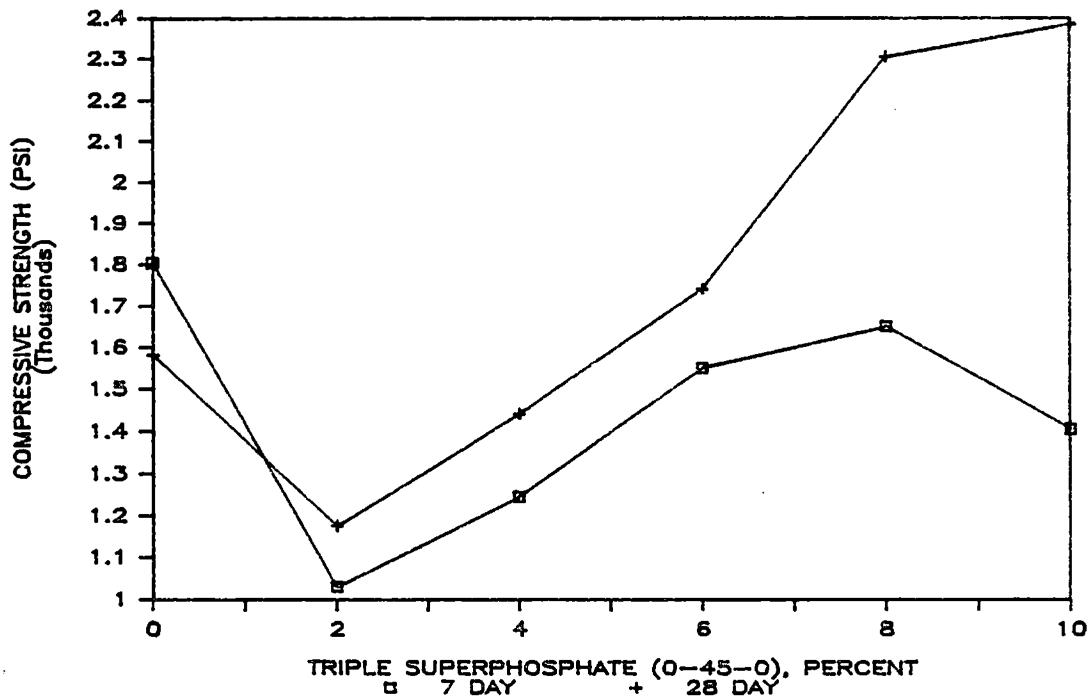
AMES FLY ASH

WATER FLY ASH RATIO = 0.24



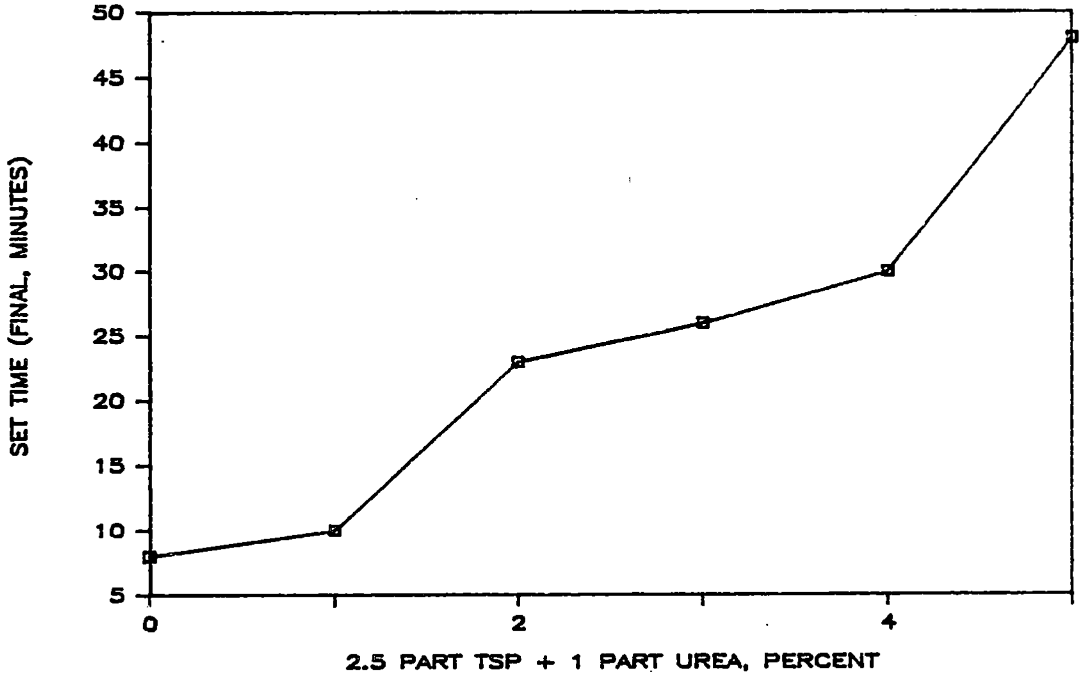


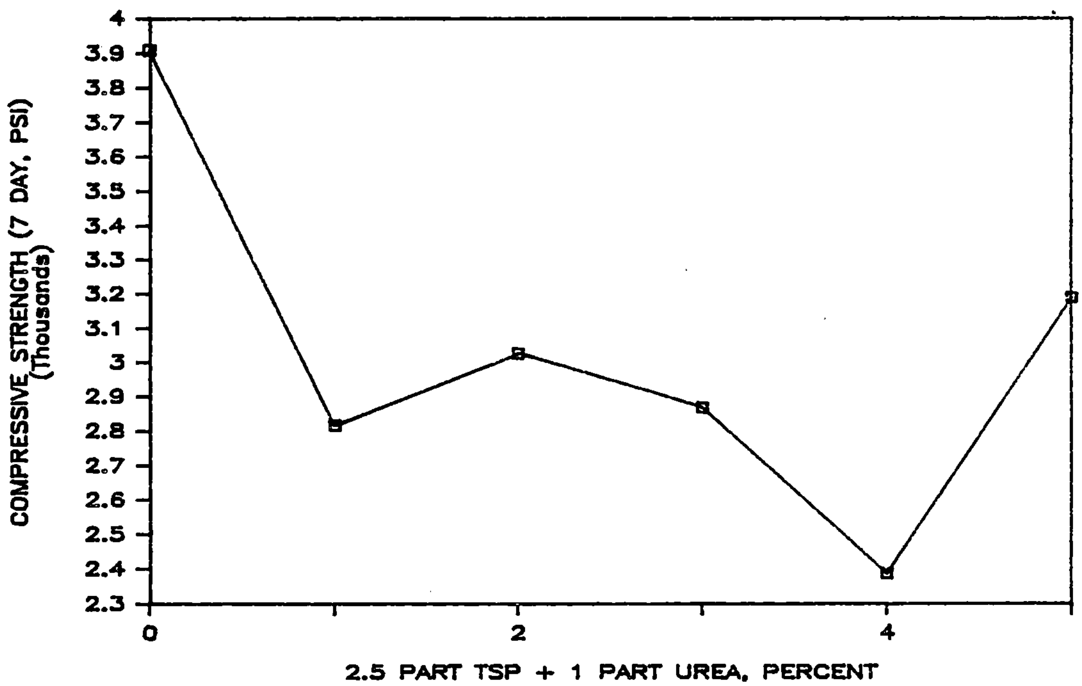

AMES FLY ASH
WATER FLY ASH RATIO = 0.30
SET TIME (FINAL, MINUTES)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
0
2
4
6
8
10
TRIPLE SUPERPHOSPHATE (0-45-0), PERCENT


COMPRESSIVE STRENGTH (PSI)
(Thousands)
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0
2
4
6
8
10
TRIPLE SUPERPHOSPHATE (0-45-0), PERCENT
□ 7 DAY
+ 28 DAY

AMES FLY ASH

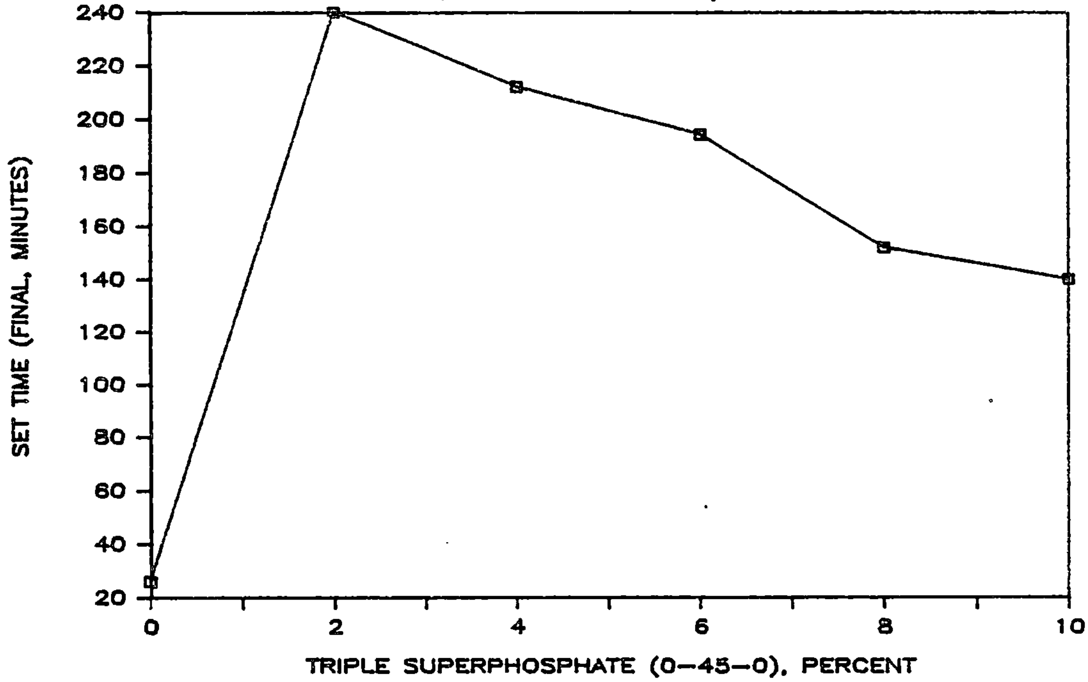
WATER FLY ASH RATIO = 0.24

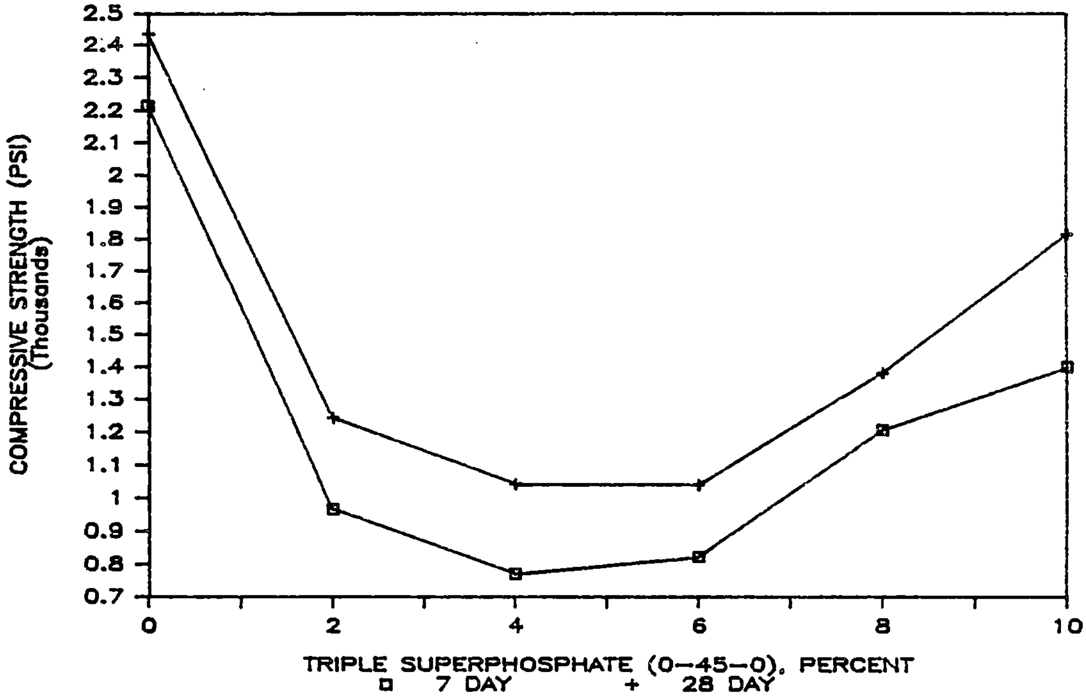




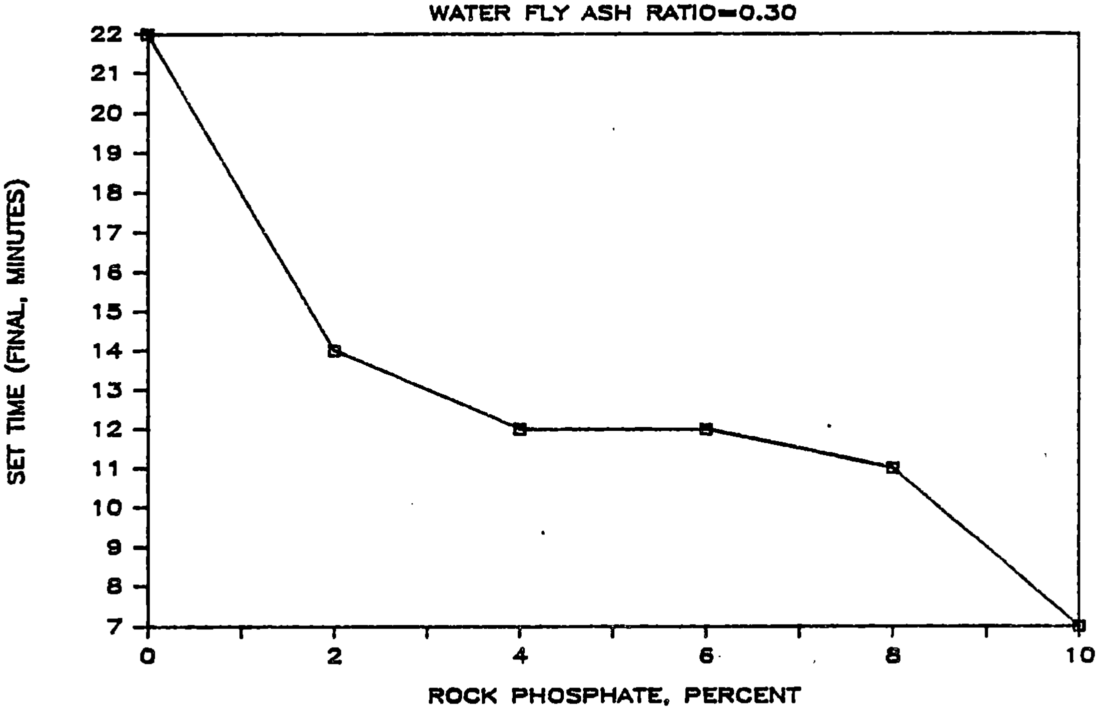
AMES FLY ASH

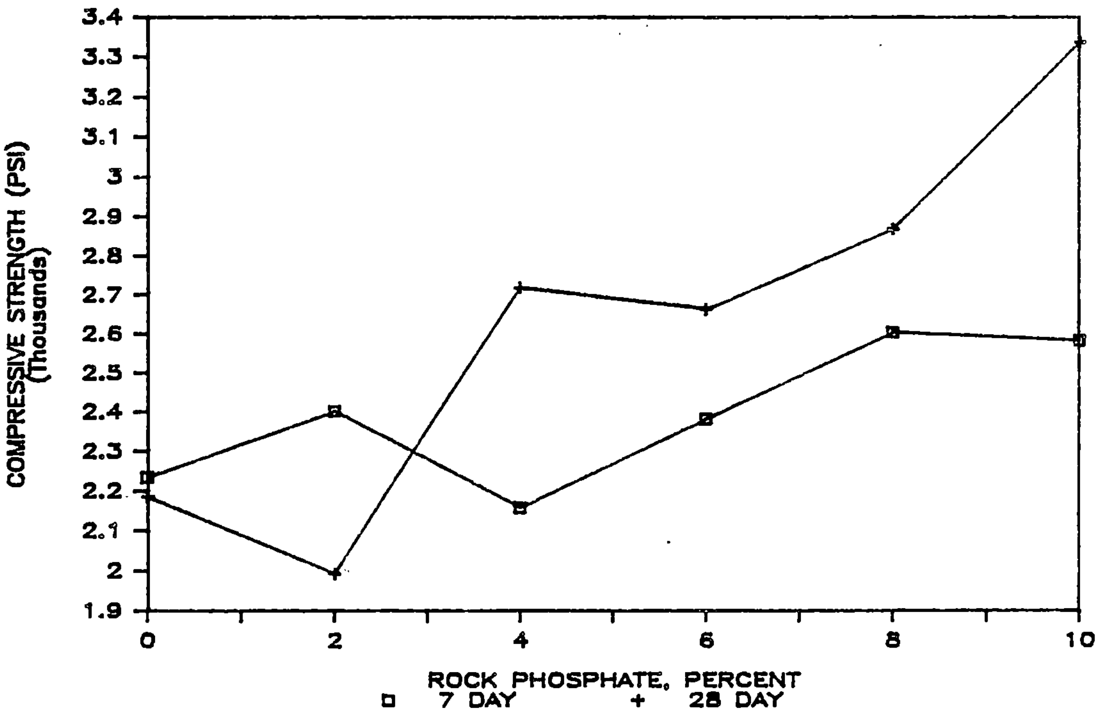
WATER FLY ASH RATIO = 0.30, LIGNIN = 2%





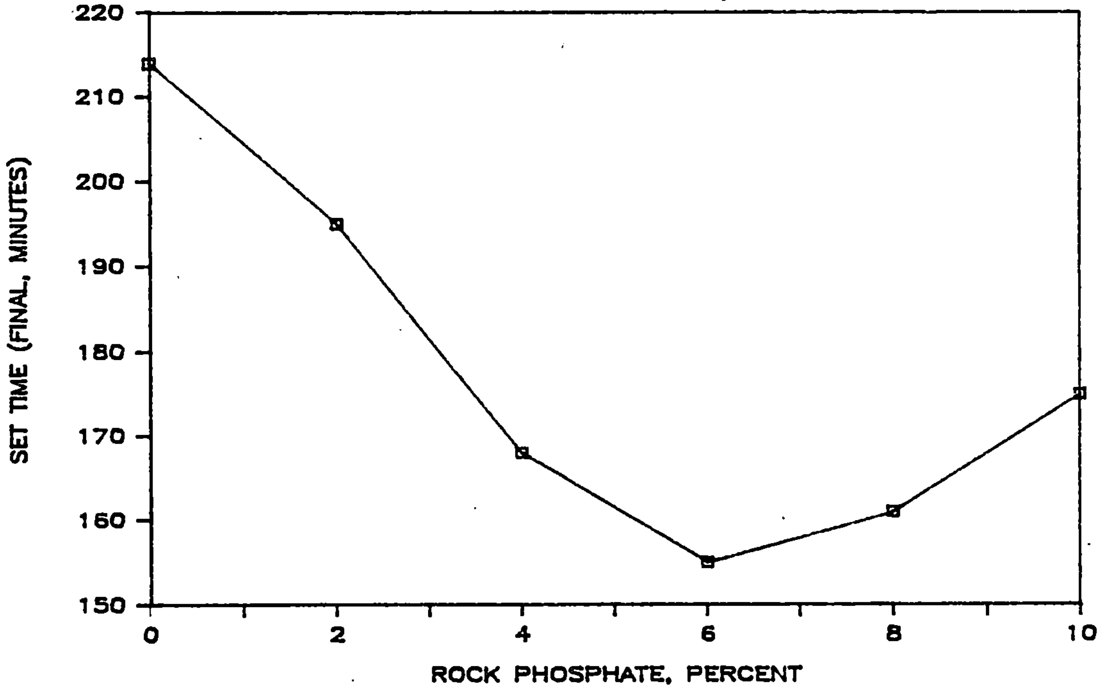
AMES FLY ASH

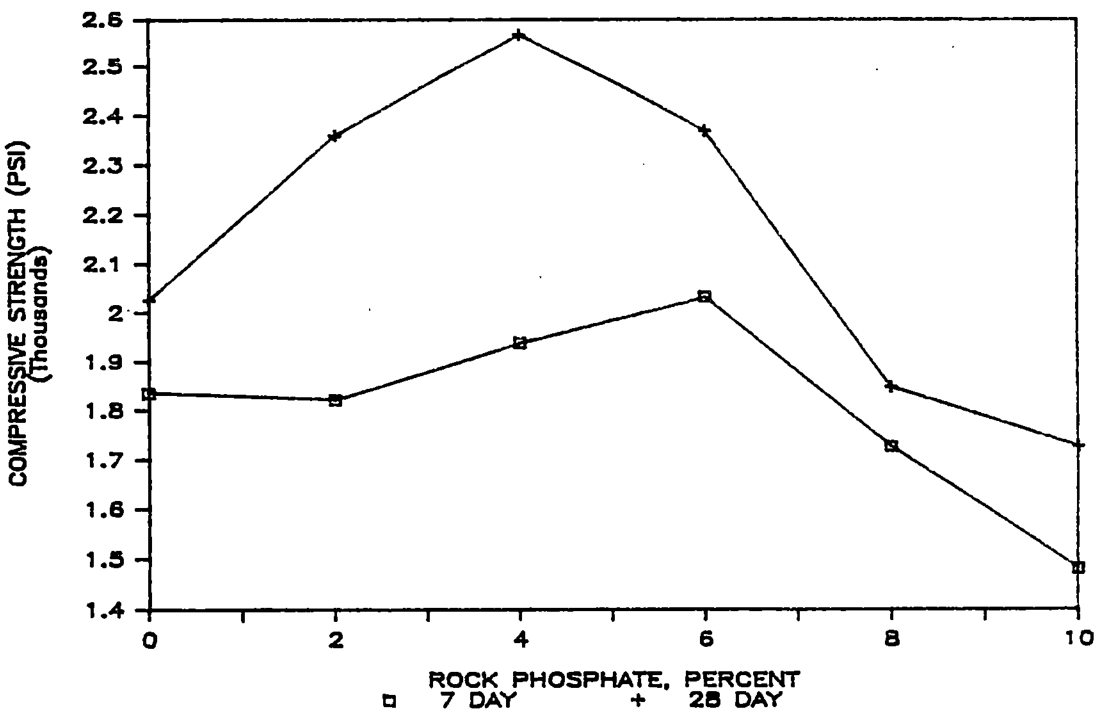

WATER FLY ASH RATIO=0.30
SET TIME (FINAL, MINUTES)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
0
2
4
6
8
10
ROCK PHOSPHATE, PERCENT


COMPRESSIVE STRENGTH (PSI)
(Thousands)
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
0
2
4
6
8
10
ROCK PHOSPHATE, PERCENT
7 DAY
28 DAY

AMES FLY ASH

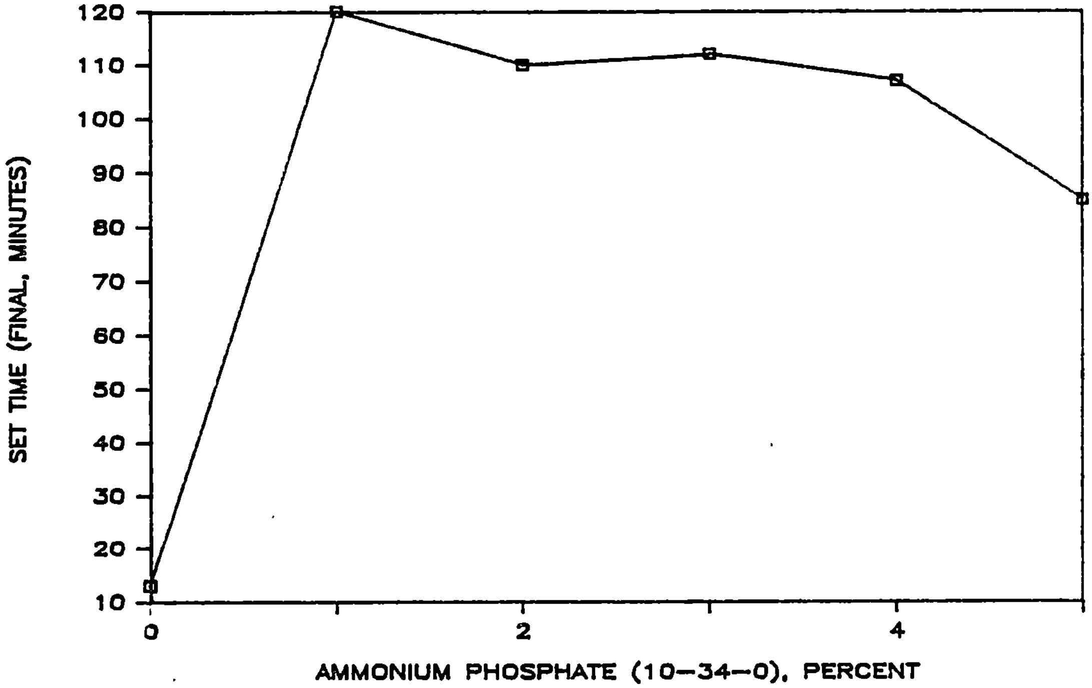
WATER FLY ASH RATIO=0.30, 2% LIGNIN

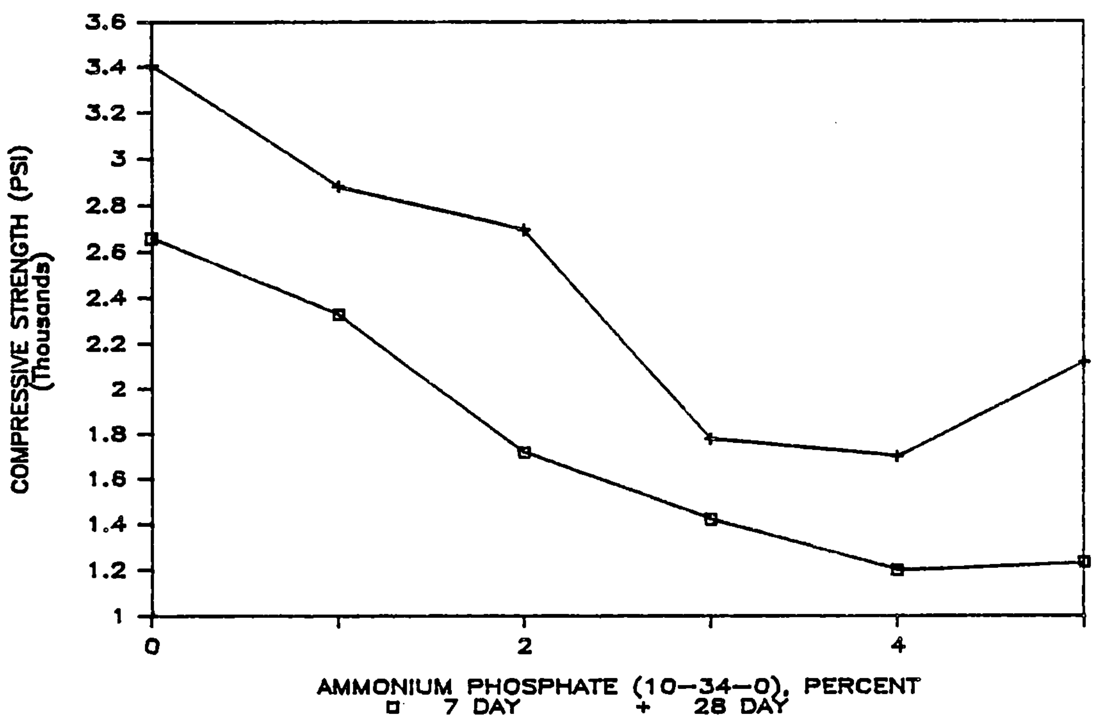




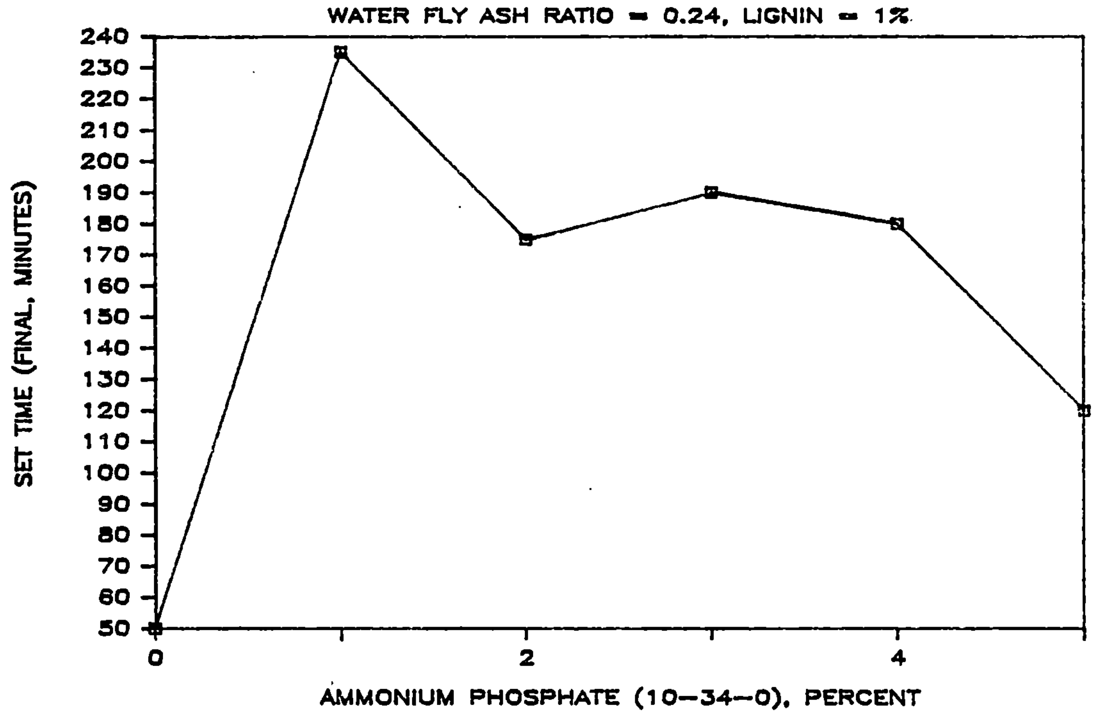
AMES FLY ASH

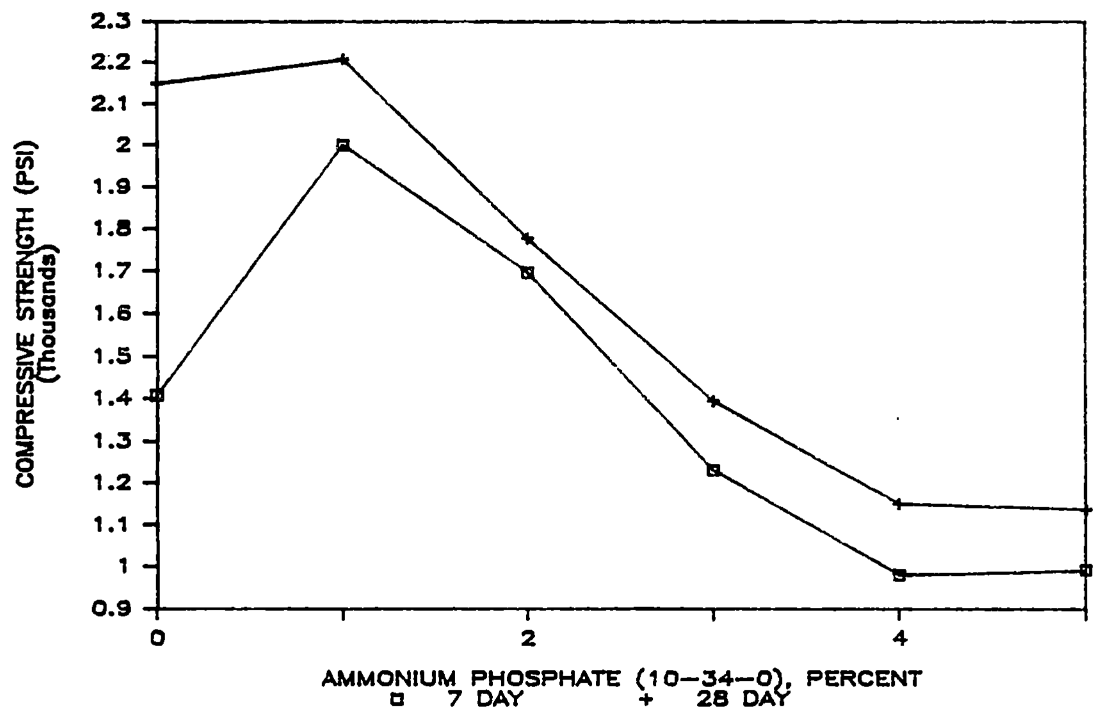
WATER FLY ASH RATIO = 0.24



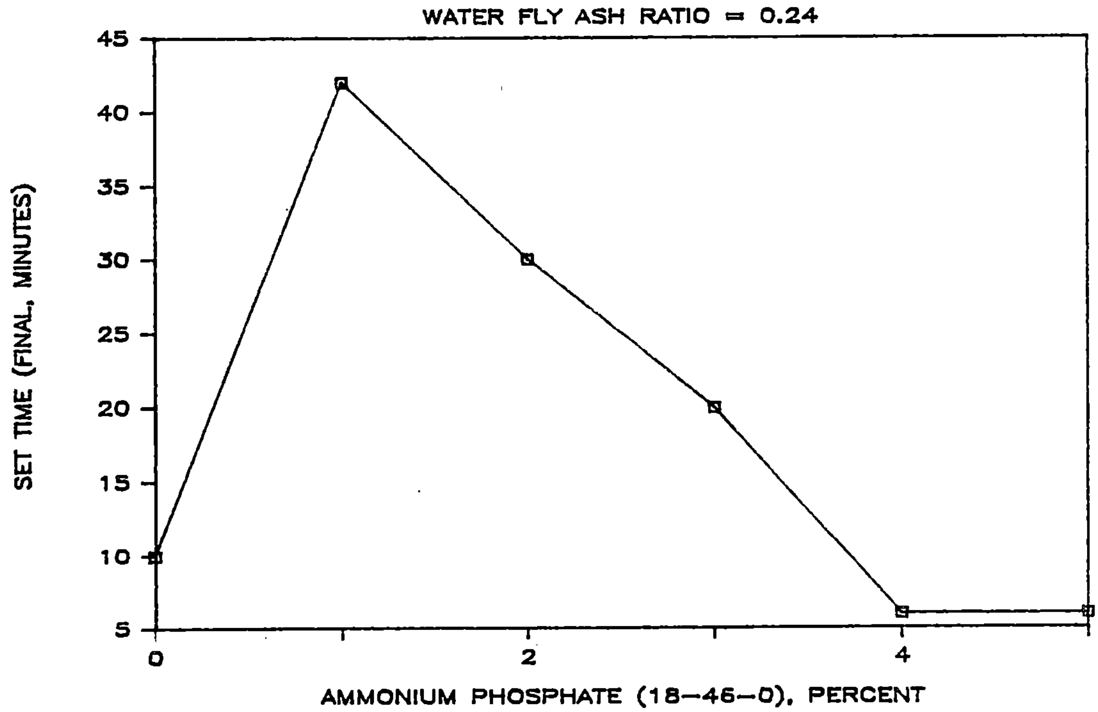


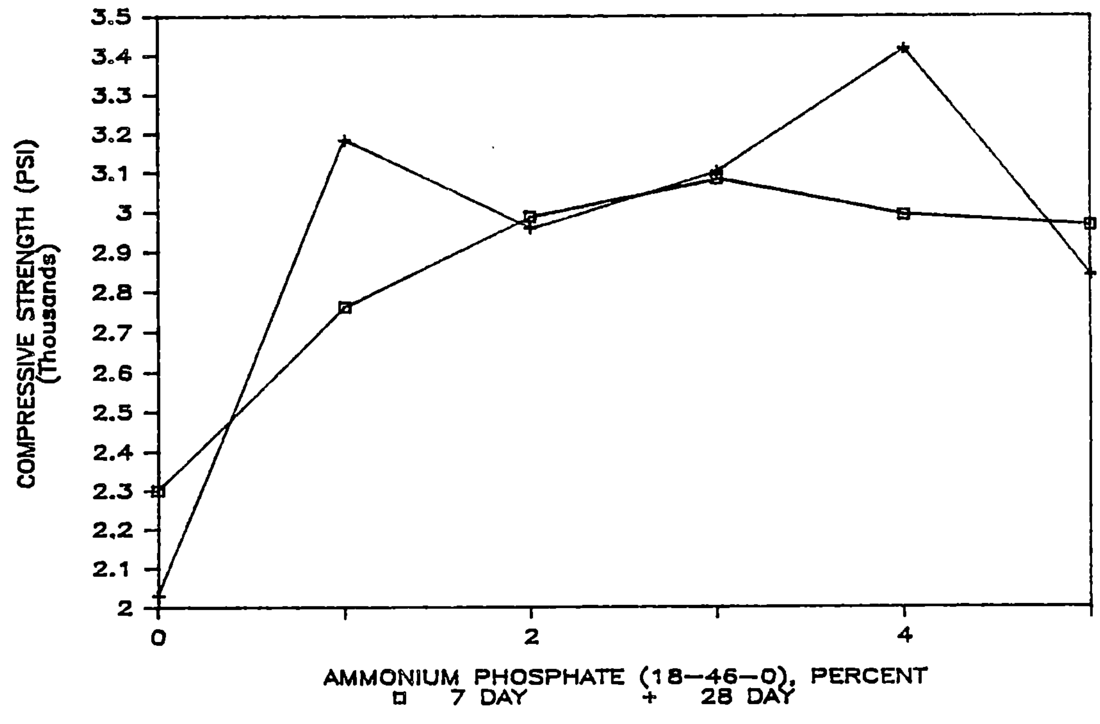
AMES FLY ASH

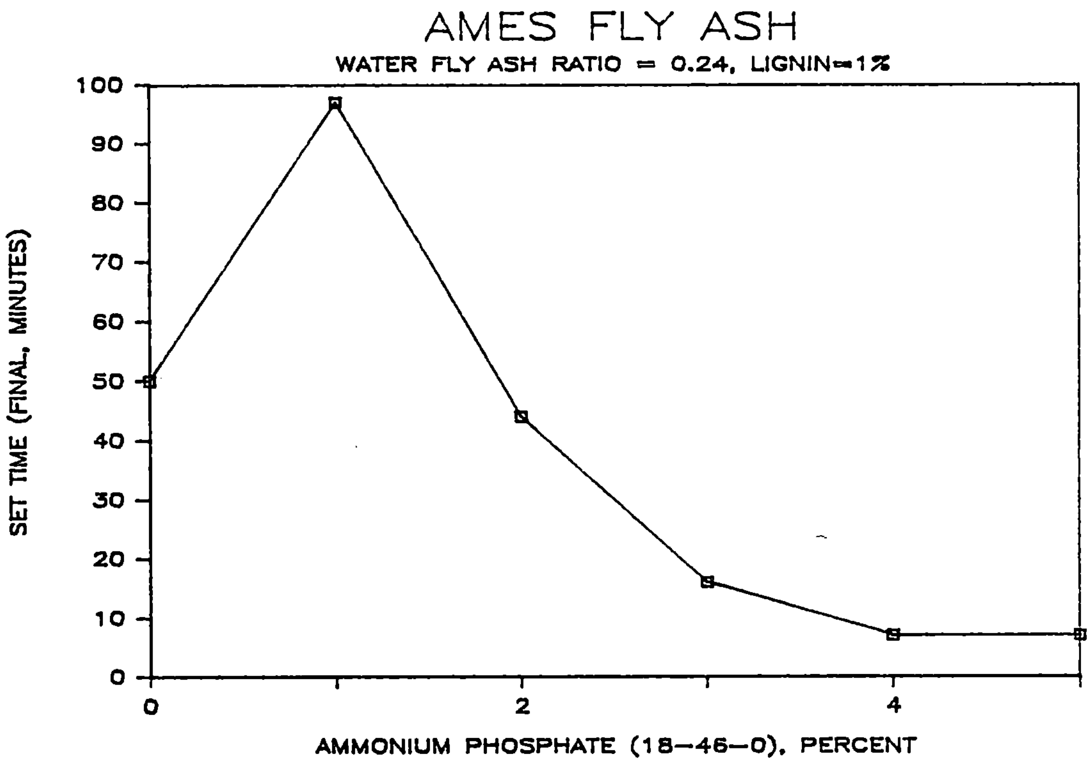

WATER FLY ASH RATIO = 0.24, LIGNIN = 1%
SET TIME (FINAL, MINUTES)
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
0
2
4
AMMONIUM PHOSPHATE (10-34-0), PERCENT

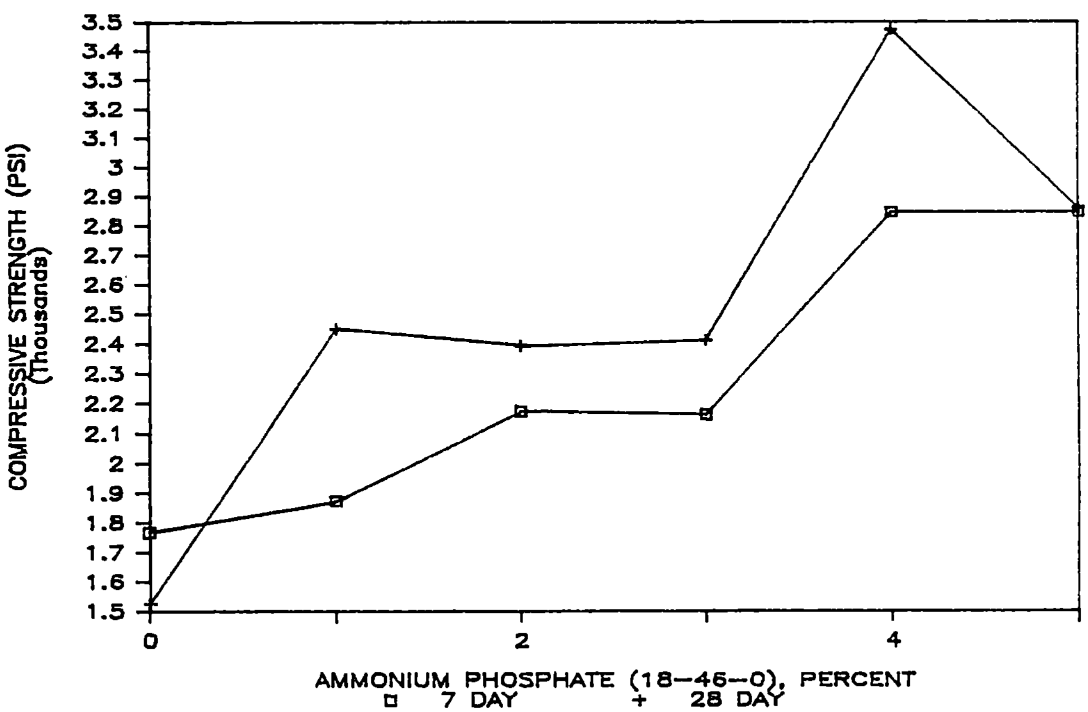

COMPRESSIVE STRENGTH (PSI) (Thousands)
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0
2
4
AMMONIUM PHOSPHATE (10-34-0), PERCENT
□ 7 DAY + 28 DAY

AMES FLY ASH


WATER FLY ASH RATIO = 0.24
SET TIME (FINAL, MINUTES)
45
40
35
30
25
20
15
10
5
0
2
4
AMMONIUM PHOSPHATE (18-46-0), PERCENT


COMPRESSIVE STRENGTH (PSI)
(Thousands)
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
0
2
4
AMMONIUM PHOSPHATE (18-46-0), PERCENT
7 DAY
+ 28 DAY


AMES FLY ASH
WATER FLY ASH RATIO = 0.24, LIGNIN=1%
SET TIME (FINAL, MINUTES)
100
90
80
70
60
50
40
30
20
10
0
0
2
4
AMMONIUM PHOSPHATE (18-46-0), PERCENT


COMPRESSIVE STRENGTH (PSI)
(Thousands)
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
0
2
4
AMMONIUM PHOSPHATE (18-46-0), PERCENT
□ 7 DAY
+ 28 DAY