Self Hardening Fly Ash

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16. Abstract

Fly ash produced in Arkansas from burning Wyoming low sulfur coal is self-hardening and can be effective as a soil stabilizing agent for clays and sands.

The strength of soil-self hardening fly ash develops rapidly when compacted immediately after mixing. Seven day unconfined compressive strengths up to 1800 psi were obtained from 20% fly ash and 80% sand mixtures.

A time delay between mixing the fly ash with the soil and compaction of the mixture reduced the strength. With two hours delay, over a third of the strength was lost and with four hours delay, the loss was over half. Gypsum and some commercial concrete retarders were effective in reducing the detrimental effect of delayed compaction.

Adequate mixing of the soil and fly ash and rapid compaction of the mixtures were found to be important parameters in field construction of stabilized bases.

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CONSTRUCTION PROCEDURES USING SELF HARDENING FLY ASH

by
Sam I. Thornton
David G. Parker

FINAL REPORT

HIGHWAY RESEARCH PROJECT 52

FHWA/AR-80/004

conducted for
The Arkansas State Highway
and Transportation Department
in cooperation with
The U.S. Department of Transportation
Federal Highway Administration

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SUMMARY

Fly ash with free lime, like that produced in Arkansas, will often react with water and self harden in a manner similar to Portland cement. The strength of the hardened fly ash usually decreases as the time between the addition of water and the compaction of the mixture increases.

In order to reduce the loss of strength in a compacted soil-fly ash mixture and test the fly ash in the field, a laboratory study and field test were made.

Laboratory Study

The fly ashes used in the laboratory study had calcium oxide contents from 20 to 30%. Particle sizes of the fly ash were in the silt size range.

Samples were mixed at 4 parts sand and 1 part fly ash by weight. The sand is uniform and ranges in size between the #4 and #200 sieve.

Sand-Fly Ash Mixtures. As the compaction delay time increased, the unconfined compressive strength of the Pueblo and Texas #1 ashes decreases. The Texas #2 sample increases in strength for the first 2 hours delay, then decreases in strength with delays of 3 and 4 hours. The decrease in strength of the Pueblo samples is from 740 psi at no delay to 100 psi at 4 hours delay and Texas #1 decreases from 1800 psi to 830 psi. The Texas #2 sample, however, increased from 1290 to 1700 psi at 2 hours delay and then decreased to 1010 psi at 4 hours delay.

Changes in maximum dry density under modified compactive effort are similar to the changes in strength. Dry density for the Pueblo sample drops from 2.07 g/cc at no delay to 1.93 g/cc at 4 hours delay. The Texas #2 sample, however, remains approximately the same at 2.12 g/cc.

Strength of the samples is sensitive to compaction water content. At no delay in compaction, a change of two percent water, either to the dry or wet side of optimum, results in strength decreases of about fifty percent. At two hours delay in compaction, the strength is still sensitive to water content and, furthermore, there is more scatter in the data.

Dry density at no delay in compaction is about as sensitive to changes in water content as are most soils. At two hours delay, the curves are similar but there is more scatter in the data.

Retarders. Gypsum effectively reduces the loss in strength due to delay in compaction of the Pueblo ash samples (Summary Table 1). In fact, 1% gypsum increases the no delay strength from 740 psi to nearly 1100 psi. At 2 hours delay in compaction, 1% gypsum has a strength of 490 psi which is the same as the no delay samples without gypsum.

Density is also increased by gypsum (Summary Table 1). The addition of 1% gypsum increases the no delay density by 0.1 g/cc. At two hours delay in compaction, samples with gypsum were less dense than at no delay but most were more dense than samples without gypsum at no delay.

PDA, a commercial retarder manufactured by Protex Industries, produces an effect similar to that of gypsum (Summary Table 1) at 2 hours delay in compaction. Strength and density are increased by the addition of 2 ml of PDA in a 1600g sample.

Field Study

A field test at SWEPCO's Flint Creek power plant was conducted to determine the effectiveness of equipment and procedures in soil-fly ash construction. Three test strips were made, each 250 feet long, con-

Summary Table 1. Effect of Retarders on Pueblo Fly Ash Samples

		Gypsum				
		0%	.5%	1%	2%	4%
No Delay	Strength(psi)	740	900	1200	630	740
	Density (g/cc)	1.93	2.02	2.06	2.03	2.02
2 Hr. Delay	Strength (psi)	500	350	500	750	350
	Density (g/cc)	1.95	1.96	1.88	2.00	1.98

		PDA Liquid				
		0	.5ml	1ml	2ml	3ml
No Delay	Strength (psi)	740	500	580	520	570
	Density (g/cc)	1.93	1.99	1.92	2.05	2.10
2 hr. Delay	Strength(psi)	500	480	760	970	1080
	Density (g/cc)	1.95	1.99	1.99	2.04	2.07

Summary Table 2. Water Contents of the Test Sections

	10% Fly Ash	20% Fly Ash	30% Fly Ash
Section 1	10.5%	9.9%	8.1%
Section 2	10.9%	8.2%	7.8%
Section 3	9.4%	6.8%	5.5%

GAINS, FINDINGS, AND CONCLUSIONS

The following conclusions are based on the results of a study using self hardening fly ash produced from Wyoming low sulfur coal:

1. Self hardening fly ash produced in Arkansas can stabilize road bases.
2. The strength of soil-fly ash mixtures may be reduced substantially by time delay between mixing and compaction.
3. Gypsum and some commercial cement retarders are effective in reducing the adverse effects of delayed compaction.
4. Fly ash stabilization works best in sands and clays because of better mechanical interlock with soil particles.
5. Fly ash characteristics vary widely. Quality control of ash used for stabilization is desirable.
6. Adequate mixing of soil and fly ash in the field is necessary.
7. Rapid compaction of soil and fly ash is necessary. Compaction should be completed within two hours after mixing.

IMPLEMENTATION

Fly ash from coal fired power plants now operating and under construction in Arkansas is a good potential resource for construction of highways. The fly ash is self hardening and can be used to stabilize road bases.

When using fly ash in Arkansas highway construction, attention should be paid to the following factors:

1. Fly ash characteristics vary widely and quality control of ash used is desirable.
2. Adequate mixing of soil and fly ash in the field is necessary.
3. Rapid compaction of soil and fly ash is necessary. Compaction should be completed within two hours after mixing with equipment heavy enough to reach the specified density.

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Introduction

Fly ash, a by-product of coal buring power plants, is effective as a soil stabilizing agent. Some fly ash, like that produced in Arkansas from Wyoming low sulfur coal, will harden when water is added and the ash is compacted. Fly ash which hardens with the addition of water only is called "self hardening" fly ash. Other fly ashes require the addition of lime to become an effective soil stabilizer.

The strength of soil-self hardening fly ash mixtures develops rapidly in compacted mixtures with water (Thornton and Parker, 1975, p.76). However, a small time delay in compaction will cause a reduction in fly ash effectiveness.

The purpose of the study reported herein is to investigate methods for minimizing the adverse effects of delayed compaction and to construct a simulated field test base course. An evaluation of various admixtures which may delay the fly ash reaction and the evaluation of rapid compaction procedures are included in the study.

Background Information

Fly Ash-General

The chemical and physical composition of a fly ash is a function of several variables:

1. Coal source;
2. Degree of coal pulverization;
3. Design of boiler unit;
4. Loading and firing conditions; and
5. Handling and storage methods.

A high degrees of variability can occur in fly ashes, not only between power plants, but within a single power plant. A change in any of the five variables can result in a change in the fly ash produced. The degree to which any change affects the potential use of the fly ash is a function of the change, and the particular application for which the fly ash might be used (Meyers, et al., May 1976, p. 9).

Table 1 is a comparison of chemical compositions of typical bituminous, lignite, and lime modified fly ashes (Cockrell and Leonard, 1970, in Meyers, 1976, p. 11).

The specific gravity of most fly ashes falls within the range of 2.1 to 2.6 (Meyers, et al., May 1976, p. 11).

Fly ash is composed of non-plastic silt sized particles spherically shaped with the median particle size ranging from 0.015 to 0.05 millimeter (Figure 1, Abdun-Nur, 1961 and DiGioia and Nuzzo, 1972).

Properties of a self hardening fly ash from a low sulfur coal obtained from Campbell County, Wyoming are shown in Table 2 (Thornton and Parker, 1975, p. vi).

Engineering Properties of Fly Ash

The compacted dry densities of fly ash are normally in the range of 70 to 95 pcf (Meyer, et al., 1976, p. 12) when determined in accordance with AASHIO T 99-74. Lower densities are often associated with high carbon content. Densities of up to 107 pcf (Joshi, September 1978, p. 208) have been reported, however. The moisture density relationship for fly ash is similar to that for cohesive soils.

The strength of fly ash depends on its self-hardening characteristics. Fly ash without self-hardening characteristics is without cohesion, except for capillary forces which may be destroyed by flooding.

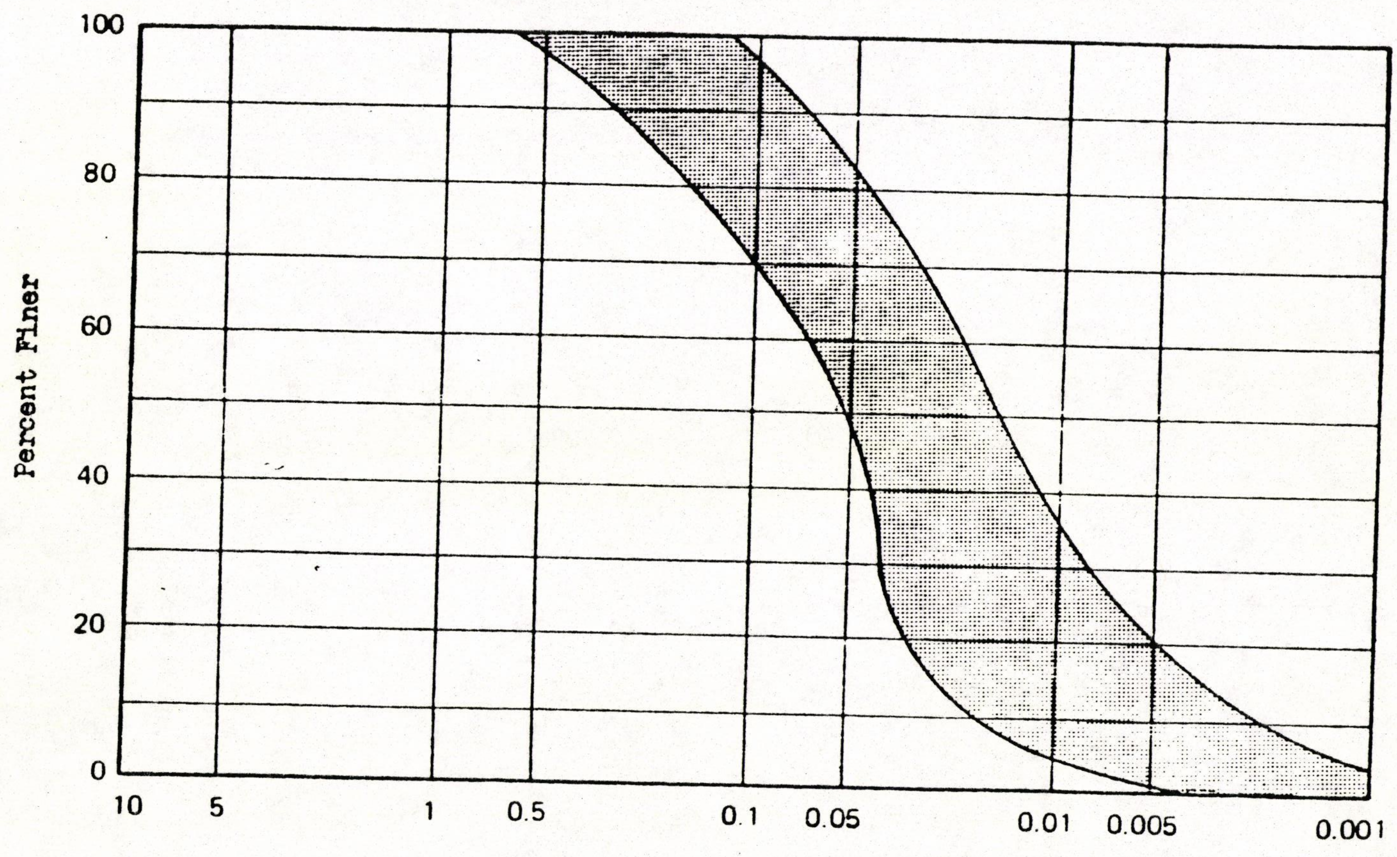


Figure 1. Grain size distribution range of most fly ashes. (From Abdun-Nur, 1961, and DiGioia and Nuzzo, 1972)

Table 1. Comparison of chemical compositions of typical bituminous, lignite, and modified fly ashes.

CONSTITUENT	PERCENT BY WEIGHT			
	BITUMINOUS ASH	LIME MODIFIED ASH	DOLOMITE MODIFIED ASH	LIGNITE ASH
SiO_2	49.10	30.85	30.81	32.60
Al_2O_3	16.25	13.70	12.54	10.70
Fe_2O_3	22.31	11.59	10.72	10.00
TiO_2	1.09	0.68	0.42	0.56
CaO	4.48	33.58	17.90	18.00
MgO	1.00	1.49	14.77	7.31
Na_2O	0.05	1.12	0.72	0.87
K_2O	1.42	0.71	0.99	0.68
SO_3	0.73	2.20	8.09	2.60
C	2.21	1.12	1.76	0.11
L.O.I.*	2.55	1.03	1.95	0.62
H_2O soluble	2.51	22.11	20.39	8.55

*Loss-on-Ignition

TABLE 2

PROPERTIES OF FLY ASH

Chemical Properties

Compound	Chemical Composition % by weight
SiO	34.0
Al_2O_3	13.0
Fe_2O_3	6.0
CaO	20.0
MgO	6.0
K_2O	0.8
Na_2O	2.8
SO_3	13.7
TiO_2	1.0
Undetermined	2.7

Physical Properties

Property	Value
Loss on Ignition	0.0%
pH	11.2%
Water Soluble Fraction	1.0%
Pozzolanic Activity Index	75.5 Kgs/sq cm
Specific Gravity	2.75
Minimum Density	1.00 g/cc
Maximum Density (Modified Proctor)	1.89 g/cc
Optimum Moisture Content	9.0%
% Passing #40 Sieve	99.5%
% Passing #100 Sieve	98.0%
% Passing #200 Sieve	94.0%
% Passing #325 Sieve	86.6%

(From Thornton and Parker, 1975, p. 35)

Self-hardening fly ash may have cohesion up to 70 psi (4.9 kg/sq.cm). The remainder of the shear strength in fly ash is due to the angle of internal friction which depends on density and ranges from 29^{o} to 46^{o}. Fly ash with self-hardening characteristics is incompressible relative to a fly ash without self-hardening characteristics (Thornton, Parker, White, 1976).

Fly ashes which do not possess self-hardening properties may consolidate quite differently from those that do possess self-hardening properties. Primary consolidation is rapid in fly ashes without self-hardening characteristics (Thronton and Parker, 1975, pp. 11-17).

Compacted fly ashes exhibit age hardening behavior (i.e., a time-dependent increase in strength after compaction). In some cases, the strength increase may be as much as 5 to 8 fold over a 3 month period. Age hardening behavior is correlated best with the presence of free lime in the fly ash (Gray and Lin, 1971, p. 12).

Vibratory compaction is best for fly ash fills. Vibratory loads probably destroy the apparent cohesion in the fly ash by breaking the surface tension of the porewater

The coefficient of permeability for fly ash depends upon its degree of compaction and the pozzolanic activity. The coefficient of permeability for some fresh self-hardening fly ashes ranges from 1×10^{-4} to 5×10^{-4} cm/sec (Parker and Thornton, 1977, p. 24).

<u>Engineering Properties of Compacted Soils</u>

Compacting soils can improve the engineering properties of soils and control the soil condition in the field. Six improvements due to compaction are listed below (ASTM, STP-377, 1965: Lambe, 1956: Sowers, 1970, pp. 204-5).

1. Compaction of the soil can reduce compressibility so that large potential settlements of structures are eliminated prior to or during the construction of the structure.
2. Compaction of soil can be used to increase the shear strength.
3. Compaction of soil can be used to control the volume change tendency of the soil.
4. Compaction of soil can decrease permeability of the soil.
5. Compaction can help to control resilience porperties of soils. The resilience properties influence pavement deflection and pavement fatigue of highways.
6. Compaction may be used to control the frost susceptibility of soils.

Factors Influencing Density

Moisture content, soil type and compactive effort influence the value of density obtained by compaction.

1. Soil Moisture Content

The optimum moisture content, at which maximum dry density is obtained, is the moisture condition at which the soil has become sufficiently workable under the compactive effort used to expel most of the air. At moisture contents less than optimum, the soil (except for cohesionless sands) becomes increasingly more difficult to work and thus to compress. As moisture contents are increased above optimum, most soils become increasingly more workable.

2. Influence of Soil Type

The nature of the soil influences the density obtained under a given compactive effort. Clay with high plasticity may be compacted through a relatively wide range of moisture contents below optimum water content with relatively small changes in density. The more granular soils produce higher density under the same compactive effort, and the density of granular soils changes rapidly with small changes in moisture content.

3. Influence of Compactive Effort

The type and distribution of the compaction effort determine the density obtained in the compaction test (Johnson and Sallberg, 1962, p. 35). The greater the compactive effort, the higher the maximum density and the lower the optimum moisture will be.

Less sginificant factors which influence density are: (1) the temperature of the soils; (2) the amount of manipulation given the soil during the compacting process; (3) the natural effects of "curing", which may increase the density of the soil; and (4) the size and shape of the mold.

Uses of Fly Ash in Soil Stabilization

Fly ash can be used either alone or in combination with lime to improve the dimensional stability of soils (Thornton and Parker, 1975, p. 21).

Some significant properties that must be considered when fly ash is used in structural fills or roadways are:

1. Fly ash displays an optimum water content at which the greatest density is achieved for a given compaction energy in a similar manner as cohesive soils (Faber and DiGioia, 1976, p. 15).
2. The individual fly ash particles are spherical in shape (Seals, 1976, p. 32).
3. Fly ash possesses a silty texture, a specific gravity less

than that of most naturally occurring soils, and no placticity. The shear characteristics of fly ash are somewhat similar to those of a cohesionless soil, a significant undrained angle of internal friction (25+ degree), and a minimal cohesion intercept in a dry condition (Lewis, 1976, p. 21).

Fly ash, produced in western Pennsylvania, has an almost linear relationship between the angle of internal friction and dry unit weight of fly ash (Faber and DiGioia, 1976, p. 15). The shear strength of fly ash depends on the degree of compaction. Pennsylvania fly ash behaves much like a cohesive soil in terms of consolidations, and compaction can significantly reduce the compressibility of fly ash (Faber and DiGioia, 1976, p. 17). Permeability for western Pennsylvania fly ash depends on the degree of compaction and pozzolanic activity.

Fly ash, produced from Wyoming low sulfur coal, reduces the permeability of clay and sandy soils. Increased compactive effort increases density and reduces permeability in soils (Thornton and Parker, 1976, p. 21).

Unconfined compressive strength is frequently used to evaluate the quality of cured lime-fly ash mixtures. The Transportation Research Board (National Cooperative Highway Research Program 37, 1976, p. 10) reported typical strengths for various lime-fly ash mixtures (Table 3). ASTM Procedure C 593-69 requires a minimum compressive strength of 400 psi for lime-fly ash in nonplastic mixtures used in base and subbase pavement.

Compressive strength development continues in lime-fly ash mixtures for a substantial period of time following placement. Strength data for a typical lime-fly ash mixture is shown in Figure 2 (National Cooperative

28 Day Immersed Compressive Strength	
Material	psi
Gravels	400-1300
Sands	300- 700
Silts	300- 700
Clays	200- 500
Crushed Stones and Slag	1400-2000

Table 3. Ranges of compressive strength for the lime-fly ash stabilized materials. (From National Cooperative Highway Research Program Synthesis of Highway Practice 37, 1976, p. 10)

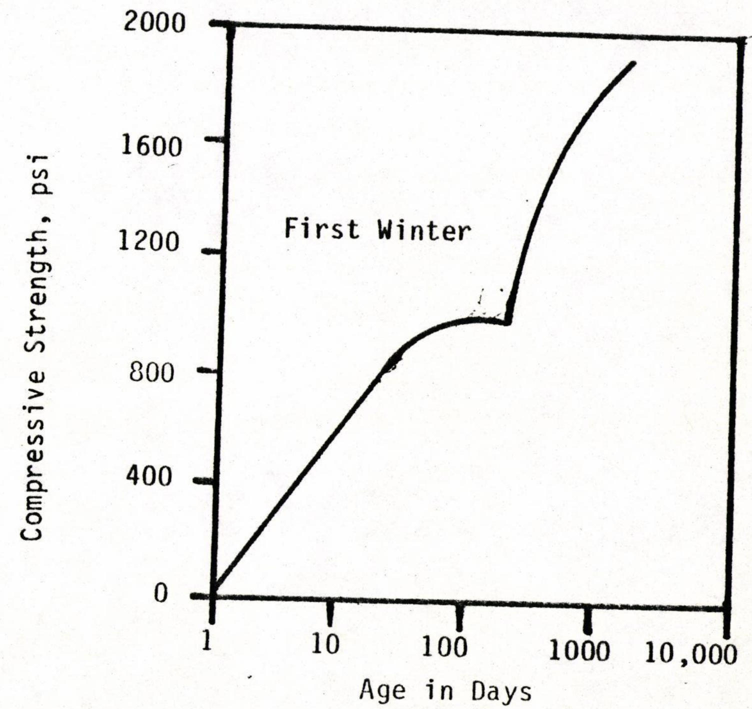


Figure 2. Compressive strength development of lime-fly ash-stabilized mixture in Chicago area. (From National Cooperative Highway Research Program 37, 1976, p. 10)

Highway Research Program 37, 1976, p. 10).

Some other properties of lime-fly ash mixtures are flexural strength, modulus of elasticity, Poisson's ratio, fatigue properties, healing, and durability (National Cooperative Highway Research Program 37, 1976, pp. 10-15). These properties are important in pavement structural analysis and in mixture proportion selection.

Compaction Characteristics of Soil-Lime-Fly Ash Mixtures

Field compaction is one of the most important steps in the stabilization of soils. Several factors that affect field compaction are: water content, effort of compaction, temperature of mix materials and effect of delay in compaction after mixing.

A laboratory investigation conducted by Manual Mateos and D.T. Davidson (1963, p. 27) on soil-lime-fly ash mixtures found the best compacting moisture for maximum strength is on the dry side of the optimum moisture content in sandy soil and on the wet side in clayey soils. For clayey soils, compaction should be completed not later than 4 hours after wet mixing, whereas for stabilized sand, compaction could be delayed until the next day without appreciable loss of strength for the fly ash tested.

Effect of Delayed Compaction

If interruptions in road construction occur after lime or fly ash are mixed with soil and water, the density and strength of the stabilized soil may be affected.

McDowell (1959, p. 64) concluded that for best hardening results, compaction to high density at the proper time is essential for all lime mixtures.

Tests on lime-stabilized expansive clay conducted in California by Mitchell and Hooper (1961) indicated that the time interval between mixing (of the soil, water and lime) and compaction could have a pronounced effect on the properties of the treated soil. For samples compacted by constant compactive effort, a delay of 24 hours between mixing and compaction led to as much as 8 pcf decrease in density and 30% decrease in as-cured strength from the values for samples compacted immediately after mixing.

Mateos and Davidson (1963, p. 38) concluded that for mixtures of gumbotil, calcitic hydrated lime and fly ash, the strength was reduced from 32 to 49 percent depending on curing period; the compacted dry density dropped about 2 pcf for 4 hours delay and about 5 pcf for 24 hours delay (Figure 3).

Research conducted by Thornton and Parker (1975, p.61) shows a small delay in compaction will cause a substantial decrease in both 7-day compressive strength and the dry density of the 80% sand and 20% self-hardening fly ash mixture (Figure 4). The rate of the reduction in strength and density grew slower with time after one hour delay in compaction.

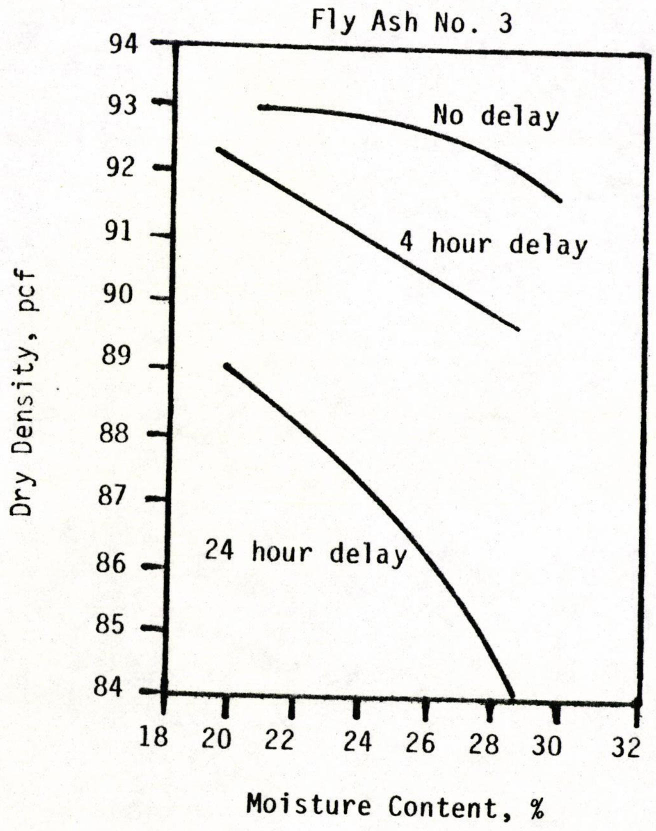
Durability of Fly Ash Stabilized Soil

Durability of a construction material is defined as the resistance to the process of weathering, erosion and traffic use over the years of exposure. Poor durability can be a problem both for natural and stabilized soils because of increased maintenance costs.

Several major factors on durability were investigated by Andres, Givala and Barenberg (1976) in order to build lime-fly ash aggregate pavements with a longer life and a lower maintenance cost:

MIXTURE PROPORTIONS

76.5% gumbotil; 6.0% calcitic hydrated lime; 17.5% fly ash



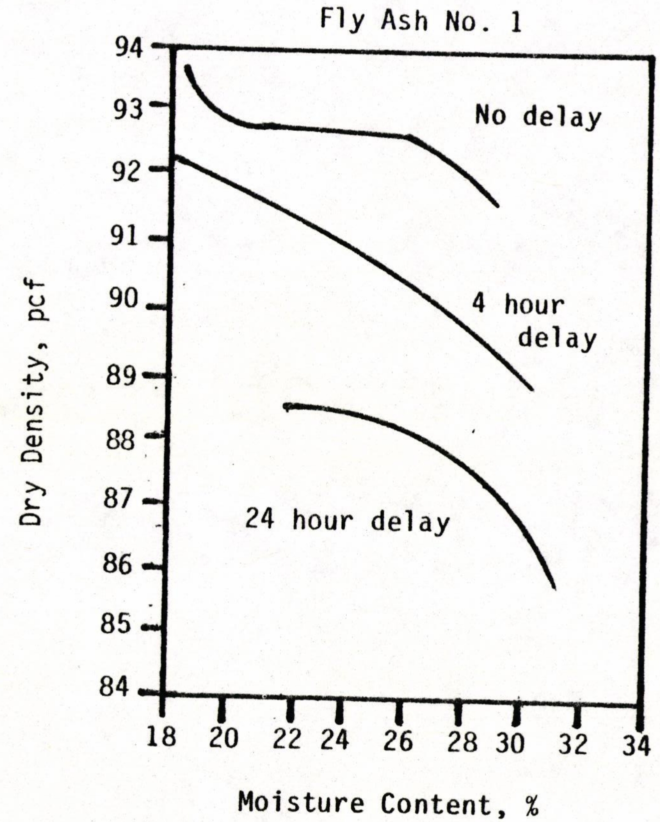


Figure 3. Moisture density relationships of lime-fly ash-soil mxitures which was compacted at different intervals of time after wet mixing. (From Highway Research Record, No. 29, 1963, p. 39)

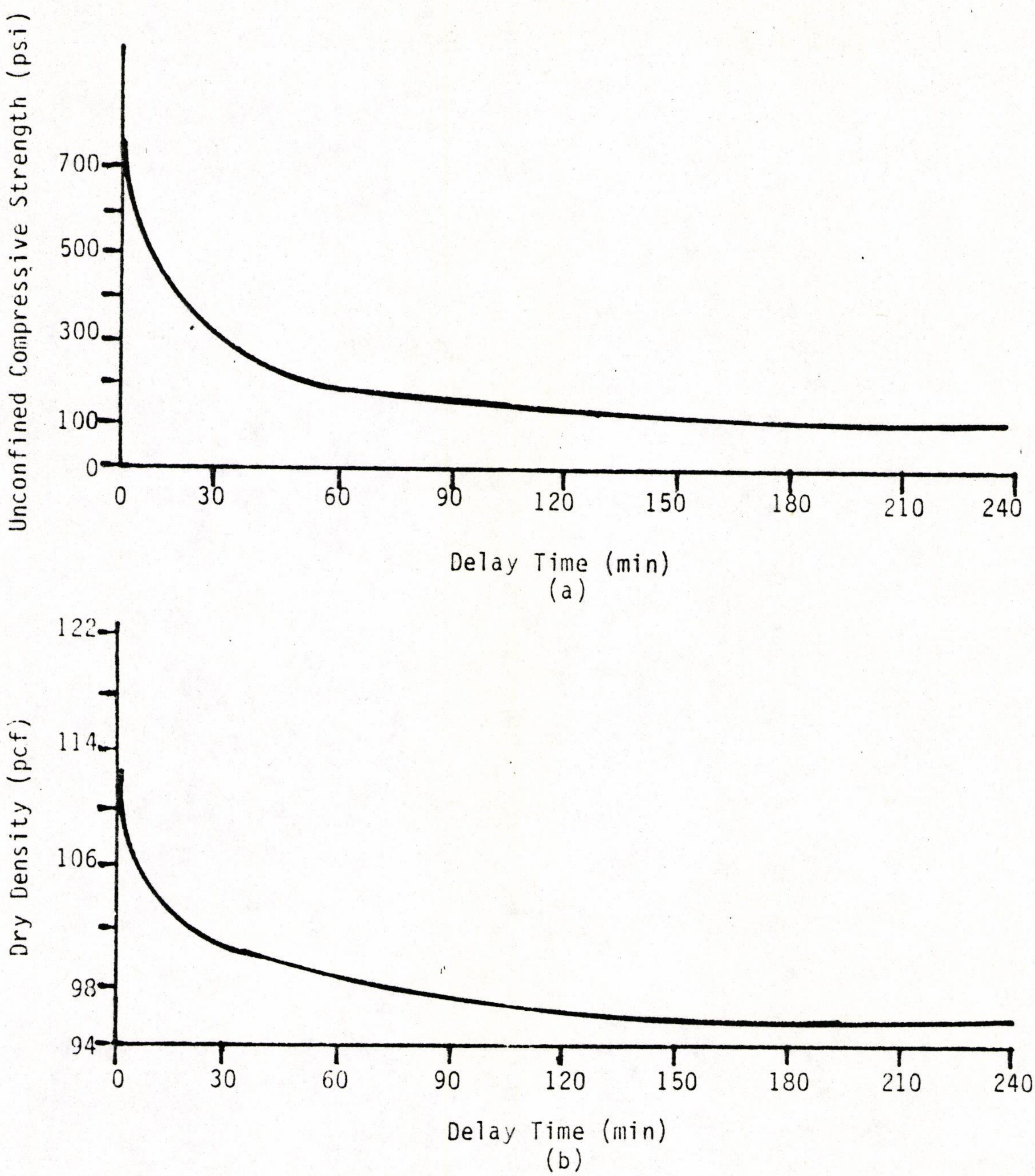


Figure 4. Effect of delay of compaction on 80% sand + 20% fly ash mixture; (a) 7-day unconfined compressive strength vs. delay time, (b) dry density vs. delay time. (From Thornton and Parker, 1975, p. 64)

1. Aggregate gradation;
2. Lime plus fly ash content;
3. Ratio of lime plus fly ash to total fines;
4. Increased curing time;
5. Fly ash content;
6. Saturation.

Durability tests of stabilized material were studied to develop a better freeze-thaw procedure (Dempsey and Thompson, 1976, p. 62). Among those methods, cyclic freeze-thaw action is the major durability factor that must be considered for lime-fly ash aggregate mixtures (National Cooperative Highway Research Program 37, 1976, p. 13).

1. Cyclic Freeze-Thaw and Brushing Test (ASTM C593-69)

This test specified in the ASTM annual book required 12 cycles of freeze-thaw, and each cycle requires brushing the specimen with 18 to 20 vertical strokes to cover the sides of the speciman: 2-4 strokes for each end of the specimen. The average compressive strength of the specimens tested and the average weight loss percentage of the specimens tested is designated as the test value for evaluation.

2. Vacuum Saturation Test

Dempsey and Thompson (1973) have developed general relations between the compressive strength of cured stabilized materials subject to vacuum saturation and the compressive strength after a 5 to 10 cycle freeze-thaw test. ASTM Committee C 7.07 has revised ASTM C 593 to incorporate the vacuum saturation testing procedure. The Standard freeze-thaw brushing test was deleted from ASTM C 593. The vacuum saturation test and data developed by Dempsey and Thompson can be used to predict the 5 to 10 cycles freeze-thaw strength by the relations shown in Figure 5. The standard error of this estimation is 67 psi for 10 cycles (Dempsey and Thompson, 1976, p. 65).

Allen et al. (January, 1977, p. 10) concluded that the vacuum saturation test is the best alternative to freeze-thaw durability testing. Allen proposed a chart (Figure 6) to obtain three cycle freeze-thaw strength from vacuum saturation strength. An additional chart (Figure 7) is proposed indicating freeze-thaw strength loss between three and seven freeze-thaw cycles.

3. Dempsey and Thompson (1976, pp. 63-5) used the cured strength and residual strength test on stabilized soils as a replacement for the standard freeze-thaw test concluding that a 68 psi tensile strength is necessary in Pennsylvania for protection against freeze-thaw.

Retarders

Sodium chloride (salt), calcium sulfate (gypsum), polymers and a variety of chemical additives have been used to retard the reactions in cement or fly ash mixtures. Thornton and Parker (1975, p. 74) reported that the addition of salt to soil-fly ash mixtures counteracted the effects of delayed compaction considerably. Gyspum (Smith, December, 1975, p. 63) was found to enhance the strength development of lime-fly ash-water mixtures.

Rapid Compaction

No literature was found on equipment which was specifically designed

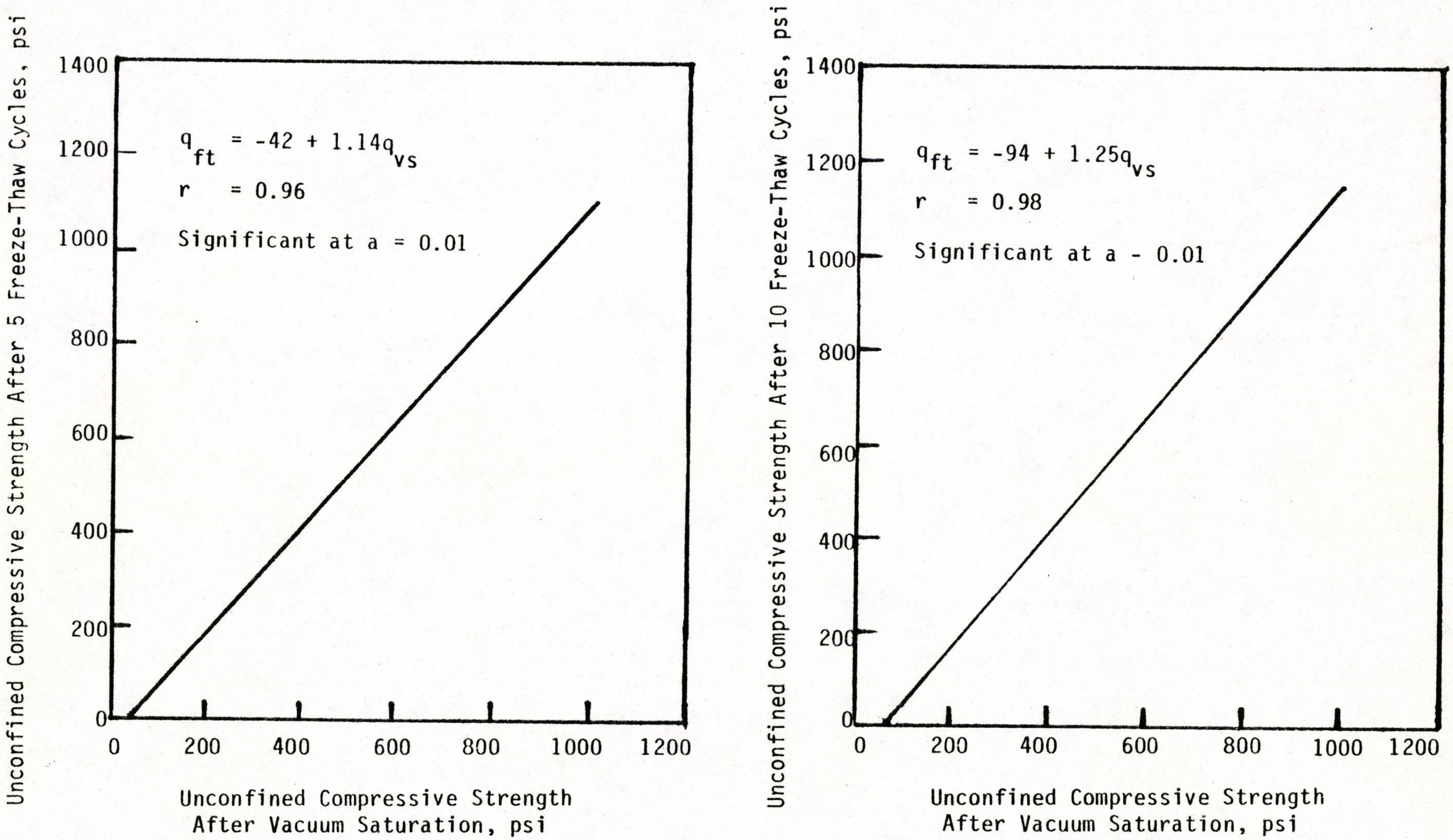


Figure 5. Relationship between vacuum saturation strength and (a) 5-cycles freeze-thaw strength, (b) 10-cycles freeze-thaw strength. (From National Cooperative Highway Research Program 37, 1976, p. 17)

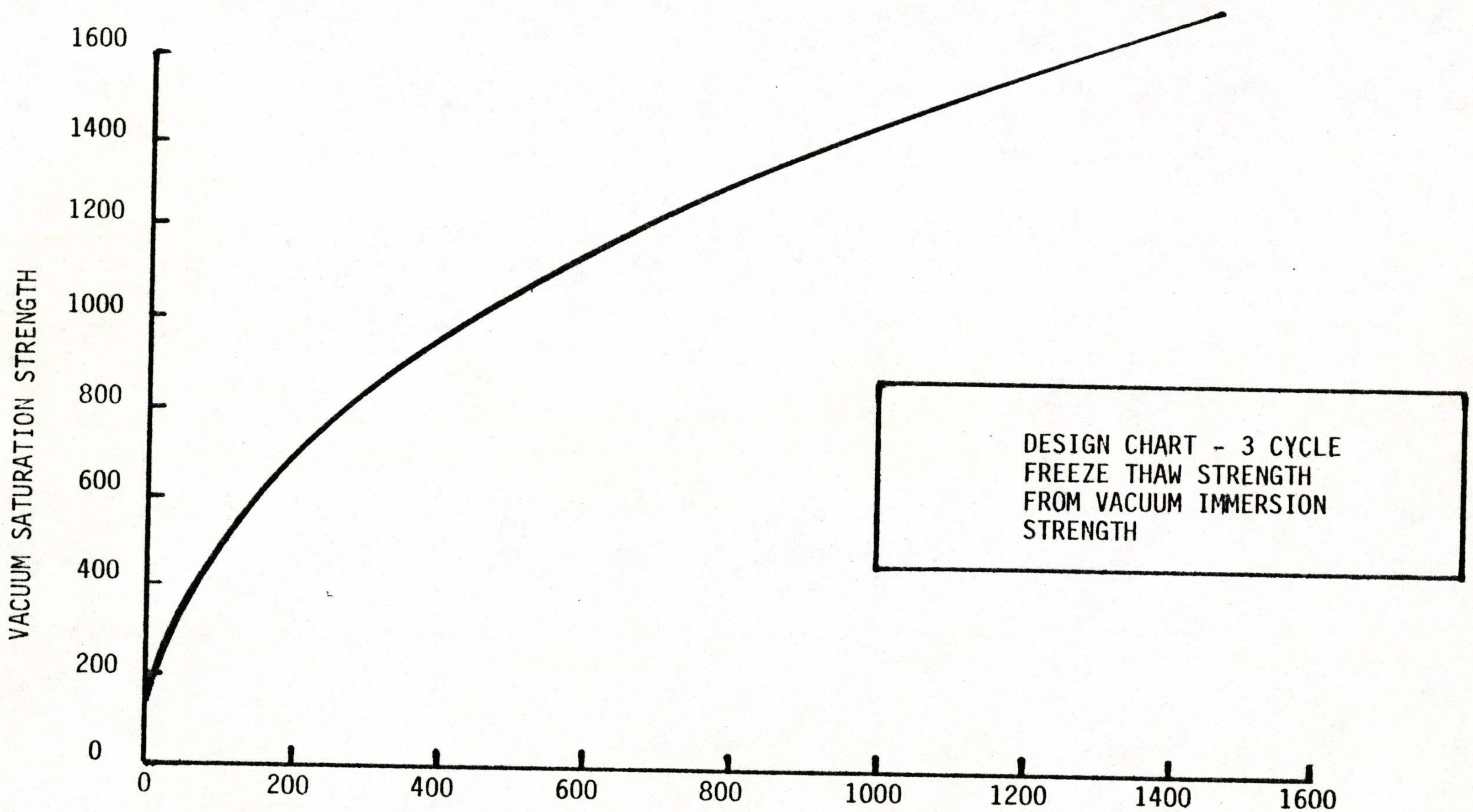


Figure 6. 3 CYCLE FREEZE THAW, KPa STRENGTH (VACUUM FLASK)

NOTE: 1 Psi = 6.894 78 KPa

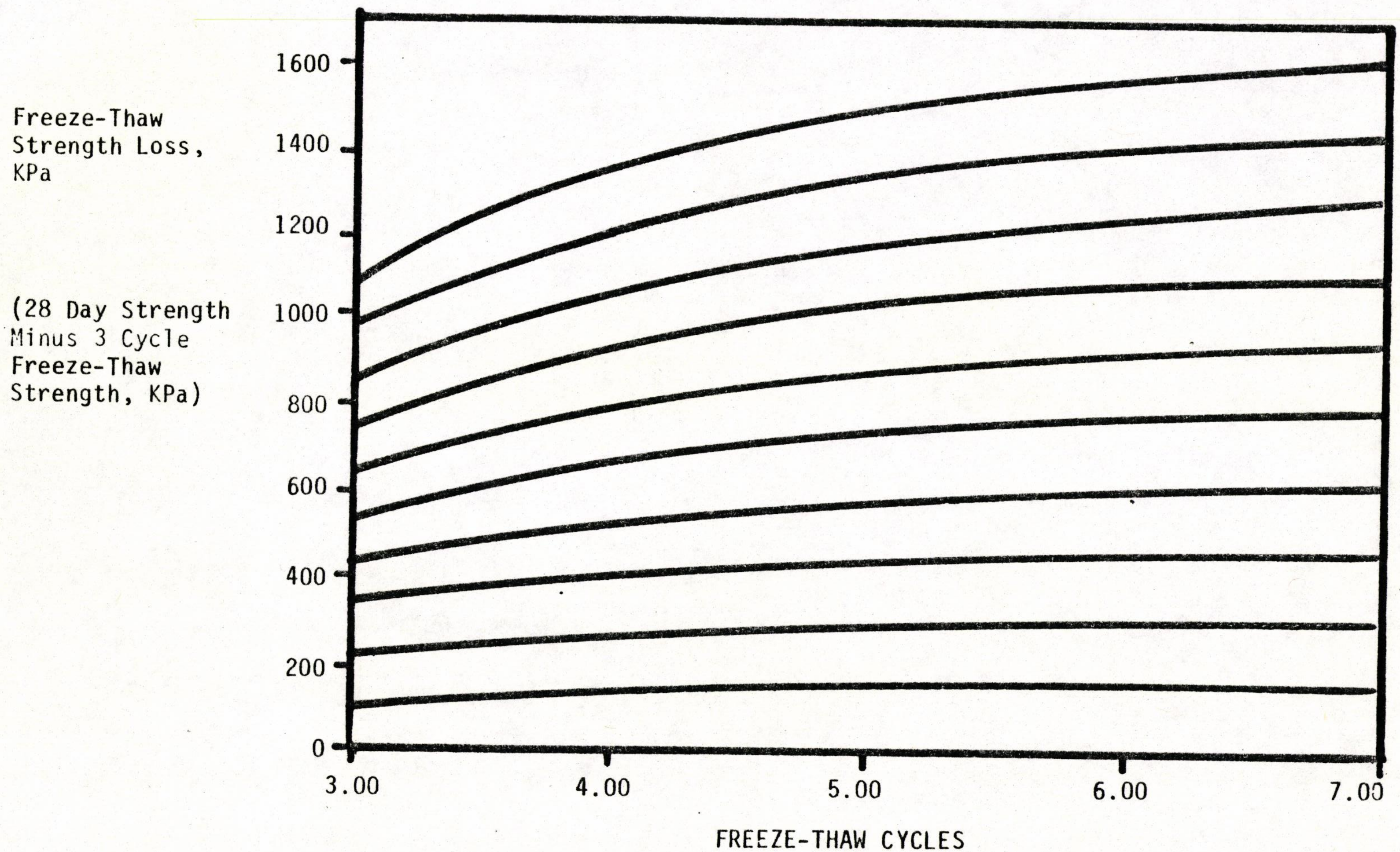


Figure 7. Design Chart. Note: 1 psi = 6.894 78 KPa

to compact soil-stabilize mixtures rapidly after mixing. A compilation of compaction equipment currently available is given in Table 4.

LABORATORY STUDY

The Laboratory Study was made to test the effectiveness of retarders in preventing strength loss as a result of delayed compaction in the soil-fly ash mixtures.

Materials Used in the Study

1. Fly Ash

Pueblo fly ash was collected by a Research Cottrell electrostatic precipitator from a 350 megawatt Combustion Engineering boiler at the Public Service Company power station in Pueblo, Colorado. Texas fly ash #1, #2, and #3 were produced in the power plant at Caison, Texas by burning subbituminous coal from Belle Ayre mine in Gillette, Wyoming. The four samples of fly ash possessed similar physical and chemical properties (Table 5). The grain size distribution curves are shown in Figure 8.

2. Soils

Two types of soil, clean sand and Flint Creek soil, were tested. The clean sand, stored in the University concrete lab, was classified SW and contained 96% sand and 4% fine gravel (Figure 9). Flint Creek soil was taken from the jobsite of the power plant at Flint Creek near Gentry, Arkansas. Flint Creek soil, classified ML, has a liquid limit of 23, plastic limit of 19, PI of 4, organic content of 1.36%, pH value of 5.8 and specific gravity of 2.64. The grain size distribution curve is presented in Figure 9.

Table 4. Compaction Equipment Compilation

Compactor		Frequency Vibrations Vib/min	Speed mph	Drum Size Dia.Width inches	Weight on Drum lb	Max Dynamic Force	Max Total Applied Force	Total Applied Force per in. width Drum
Ferguson	SP-75B	1200-1800	2.4-15.0	60 84	11400	37175	48575	578
"	SP-230	1100-1500	1.2-9.2	66 78	20200	46031	66231	849
Bros	SPV-627VA	900-2000	0-8.0	54 72	6660	27000(min)	33660(min)	468(min)
RayGo	400A	1100-1500	0.17.0	59 84		27000	47000	560
"	410A	1100-1500	0-8.0	59 84		27000	48400	576
"	500A	1100-1500	0-17.5	60 80		45000	76000	950
"	600A	1100-1500	0-17.5	60 100		45000	63000	630
"	700A	1100-1500	0-12.0	60 100		60000	105500	1055
"	304A	1200-2300	0-13.0	48 66		16000	28000	424
"	404B	1200-2300	0-17.5	59 84		27000	44080	525
Ingersoll-Rand	SP54	1800	0-15.0	54 85	10400		35600	419
"	SP42	2100	0-15.0	42 72	6150		21200	294
"	SP60	1400	0-10.0	60 100	21500		61500	615
Tampo	VP-200	1100-1500	1-15.0	54 80				

Compiled by Sam Smith, AHTD

Table-5. Properties of Fly Ash. (From Thornton, Parker & White, 1975, p. 4).

Chemical Analysis of the Fly Ash.[a]

	Chemical Composition, % by weight
SiO_2	34.0
Al_2O_3	13.0
Fe_2O_3	6.0
CaO	20.0
MgO	6.0
K_2O	0.8
Na_2O	2.8
SO_3	13.7
TiO_2	1.0
Undetermined	2.7
	100.0

Physical Properties of the Fly Ash.[b]

Loss on Ignition	0.0%
pH	11.2
Water Soluble Fraction	1.0%
Pozzolanic Activity Index	1074.3 psi
Specific Gravity	2.75
Minimum Density	62.2 pcf
Maximum Density (Modified Proctor)	118.0 pcf
Optimum Moisture Content	9.0%
% Passing #40 Sieve	99.5%
% Passing #100 Sieve	98.0%
% Passing #200 Sieve	94.0%
% Passing #325 Sieve	86.6%

[a] Determined by Sargent and Lundy, Engineers, Chicago.

[b] Determined in the University of Arkansas Soils Laboratory.

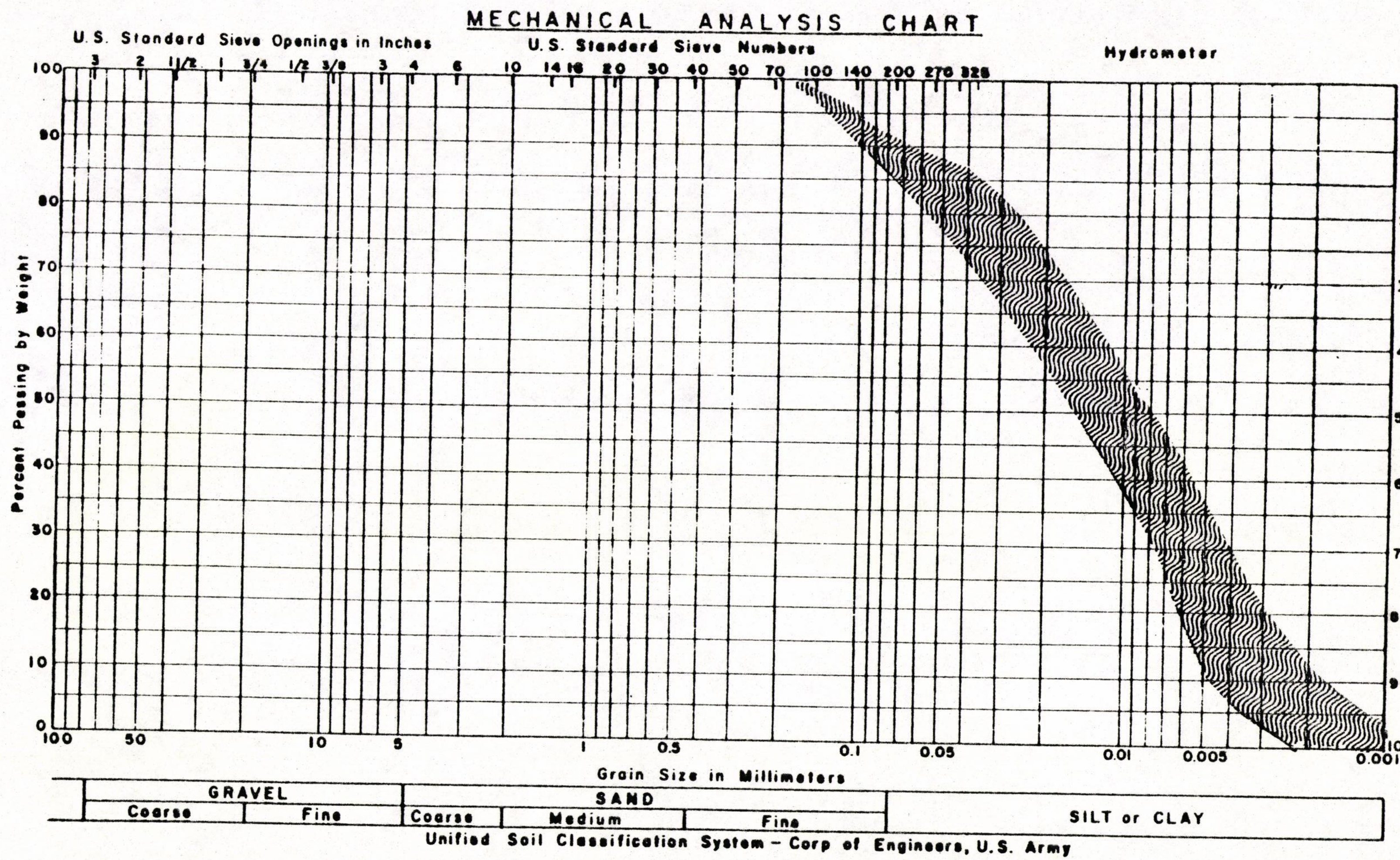
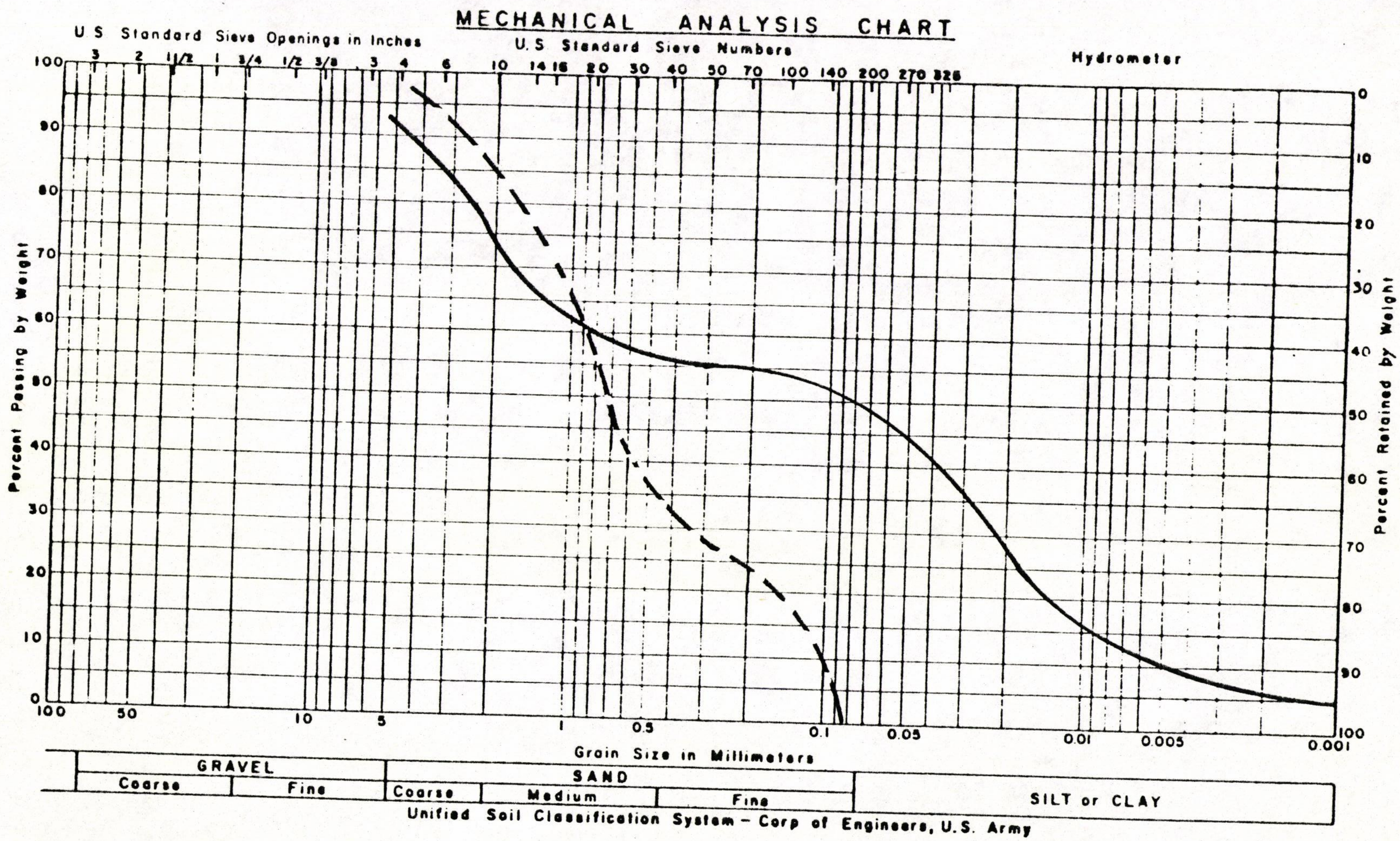


Fig-8. Grain size distribution curves of

Pueblo, Texas No.1, Texas No.2, and Texas No.3



Concrete sand

Flint Creek soil

Fig-9 Grain size distribution curves of concrete sand and Flint Creek soil

Moisture-Density Relationships

Modified Proctor Compaction Tests were conducted on sand-fly ash and Flint Creek soil-fly ash mixtures. The ratio of fly ash to soil of all specimens tested was 1:4 (20% fly ash, 80% sand in terms of total weight of the mixture) unless otherwise noted.

Different fly ash-soil mixtures were compacted immediately after wet mixing to find the moisture-density relations (Table 6).

1. Maximum dry density and optimum moisture content for sand-Pueblo fly ash mixtures was 2.10 g/cc and 5.0% respectively (Figure 10).
2. For sand-Texas fly ash #1 mixture, the maximum dry density was 2.10 g/cc, and optimum moisture content was 5.5% (Figure 11).
3. For sand-Texas fly ash #2 mixtures, the maximum dry density was 2.12 g/cc at an optimum moisture content of 5.0% (Figure 12).
4. Compaction obtained for different fly ash-sand mixtures were compared in Figure 13.
5. Flint Creek soil was compacted by Modified Proctor compactive effort. The optimum moisture content and maximum dry density obtained was 12.2% and 1.86 g/cc respectively (Figure 14a).
6. Flint Creek soil-Texas fly ash #3 mixtures had a maximum dry density of 1.91 g/cc and an optimum moisture content of 11.5% (Figure 15).

Unconfined Compressive Strength

The results of the unconfined compressive strength tests for the fly ash-soil mixtures are also shown in Table 6.

1. The sand-fly ash mixtures were compacted without time delay. The maximum 7-day compressive strength for mixtures of Pueblo fly ash,

Table 6. Compressive strength, optimum moisture content and maximum dry density of various soil-fly ash mixtures which were compacted with no delay and 2 hour delay at modified effort.

	Optimum Moisture Content (%)	Maximum Dry Density (g/cc)	7-Day Compressive Strength (psi)	Optimum Moisture Content (%)	Maximum Dry Density (g/cc)	7-Day Compressive Strength (psi)
100% Sand	5.0	1.7	0	5.0	1.7	0
80% Sand + 20% Pueblo Fly Ash	5.0	2.1	800	8.2	2.05	380
80% Sand + 20% Texas Fly Ash #1	5.5	2.1	1800	8.2	2.01	810
80% Sand + 20% Texas Fly Ash #2	5.0	2.12	1300	5.5	2.14	1740
100% Flint Creek Soil	12.2	1.86	60	-	-	-
90% Flint Creek Soil + 10% Texas Fly Ash #3	-	-	-	11.9	1.88	160
80% Flint Creek Soil + 20% Texas Fly Ash #3	11.5	1.91	390	14.5	1.82	190
70% Flint Creek Soil + 30% Texas Fly Ash #3	-	-	-	14.2	1.80	280

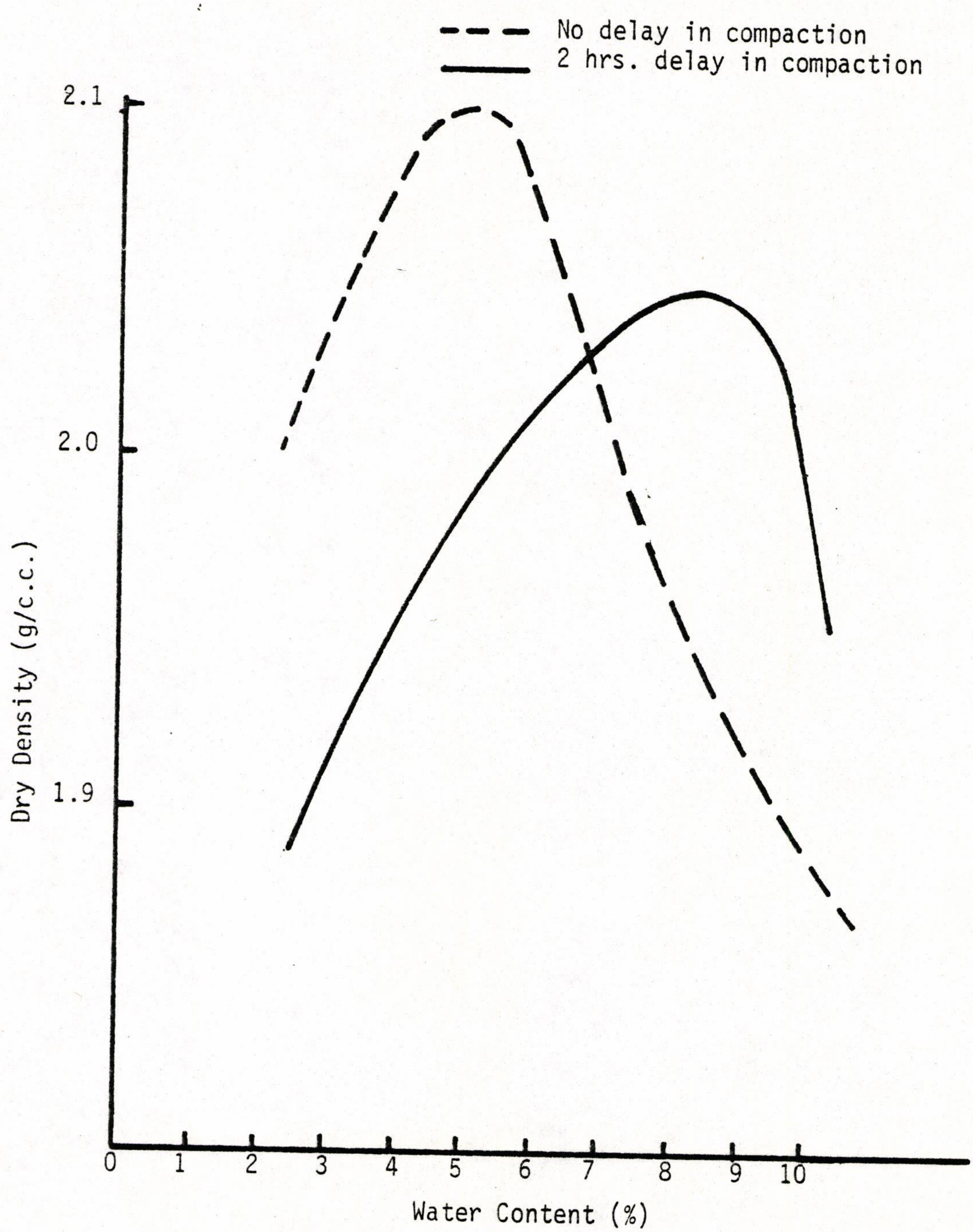


Fig-10 Moisture-Dry Density relationship of 80% + 20% Pueblo fly ash mixtures.

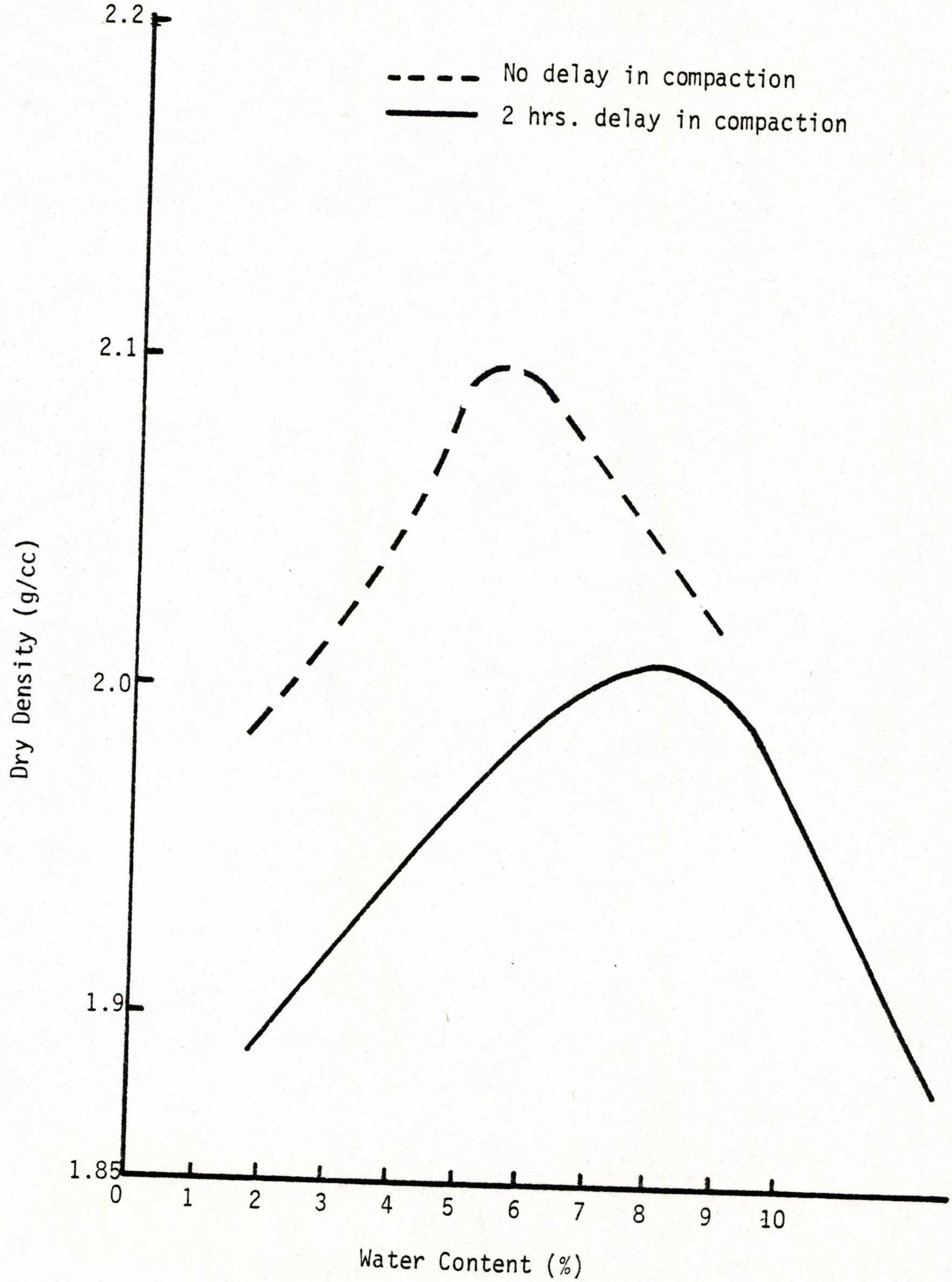


Figure 11. Moisture-Dry Density relationship of 80% sand + 20% Texas fly ash #1 mixtures.

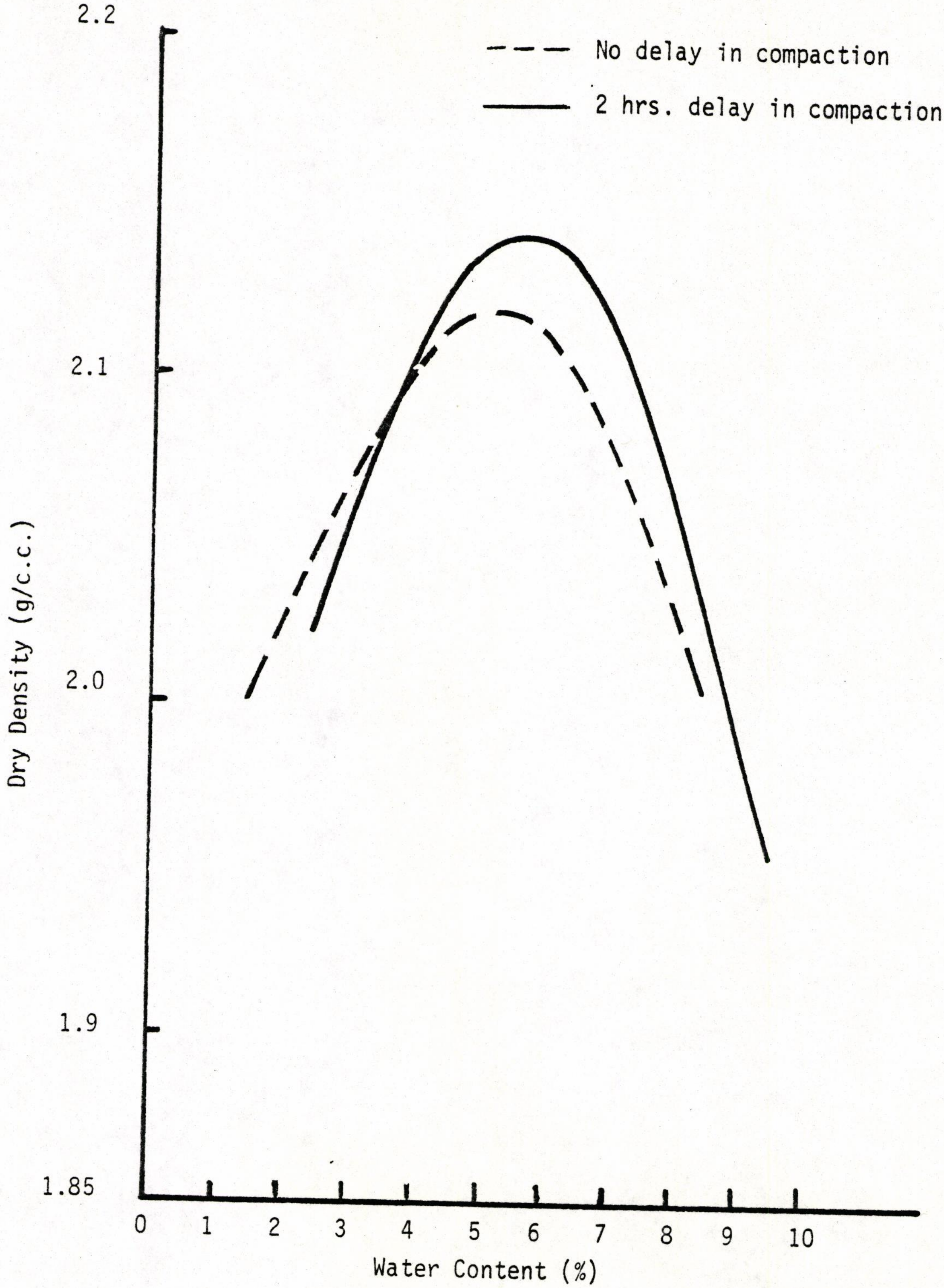


Fig-12 Moisture-Dry Density relationship of 80% sand + 20% Texas fly ash #2 mixtures.

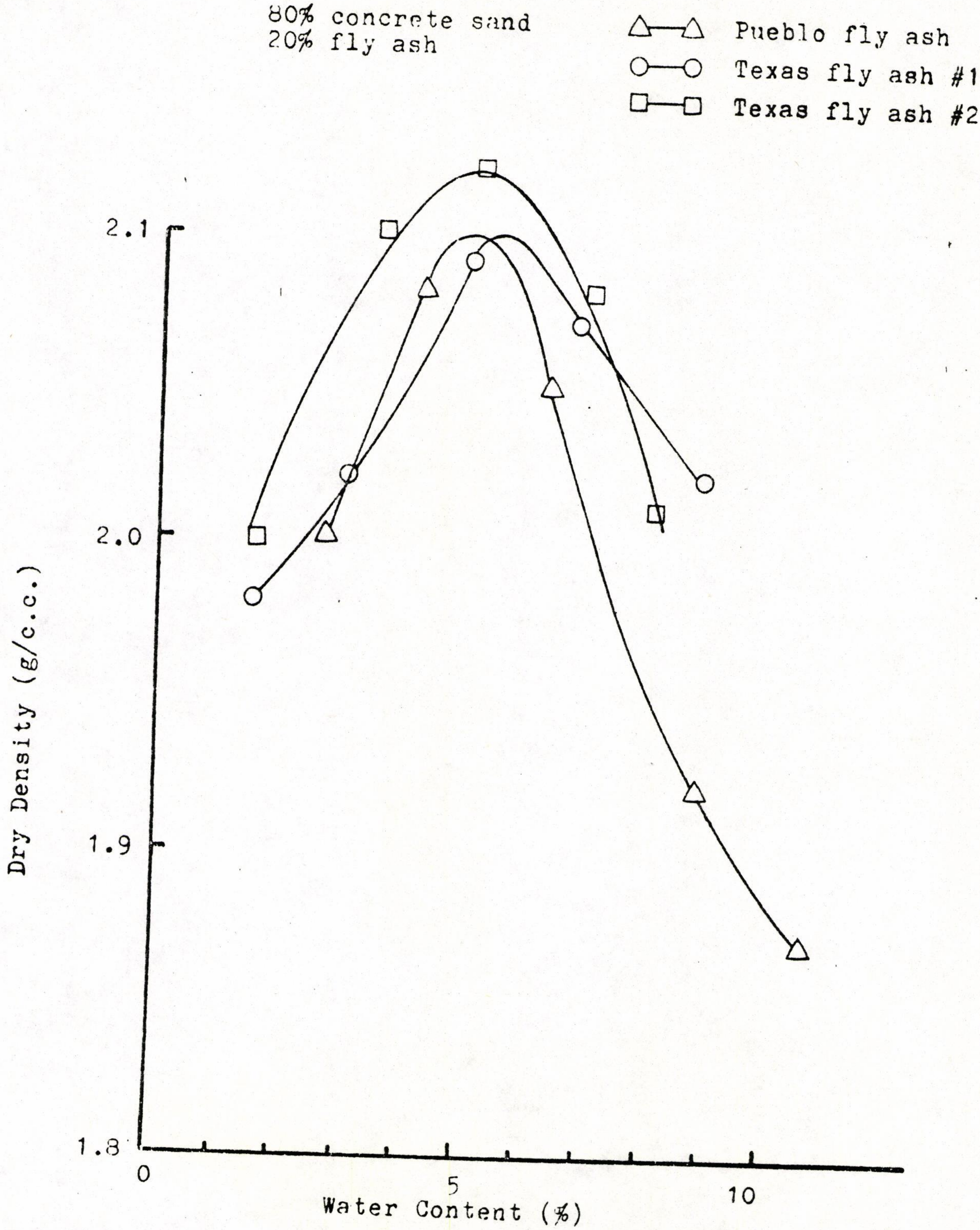
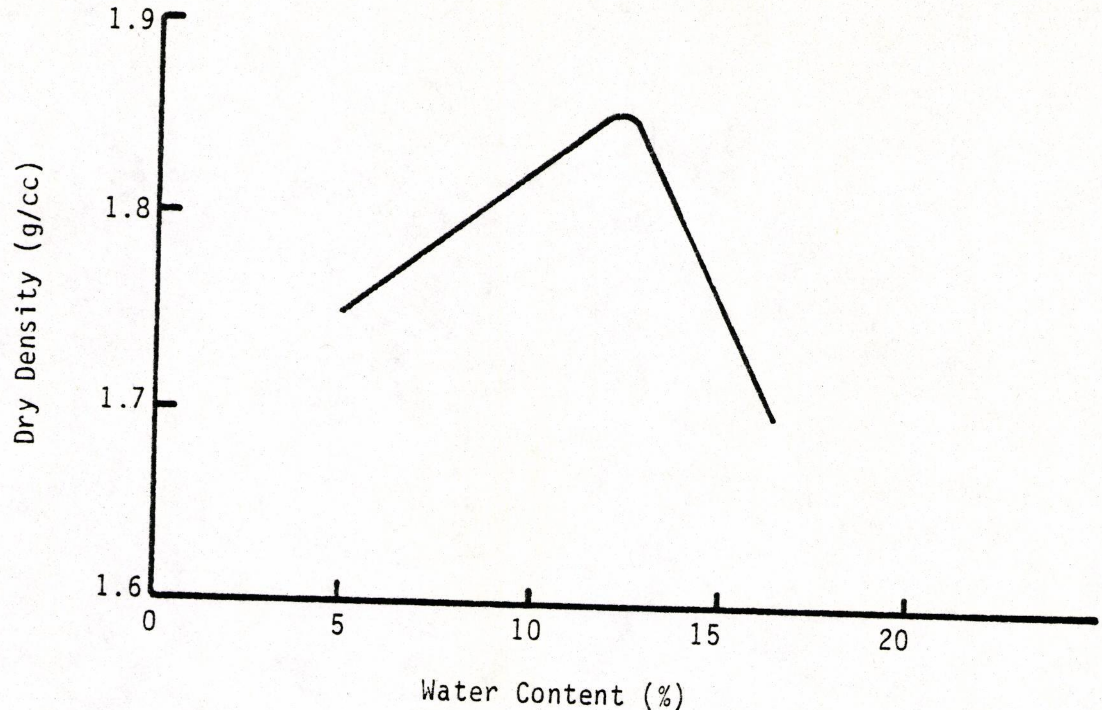
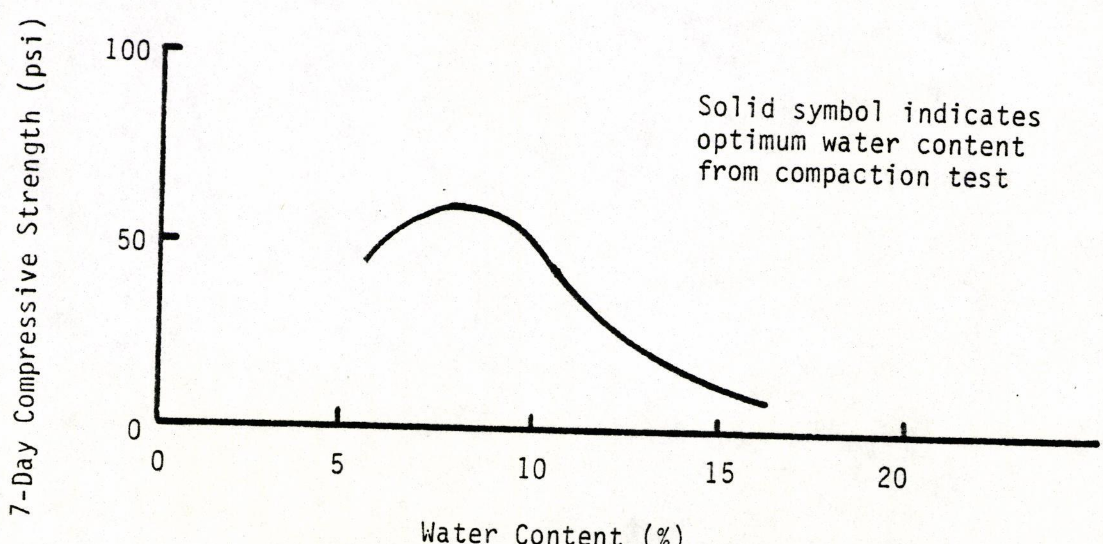


Figure 13. Relationships of dry density vs. water content for sand-fly ash mixtures which were compacted by Modified Proctor effort without time delay.



(a)



(b)

Figure 14. Modified Proctor Test on Flint Creek Soil;
(a) dry density vs. water content,
(b) compressive strength vs. water content.

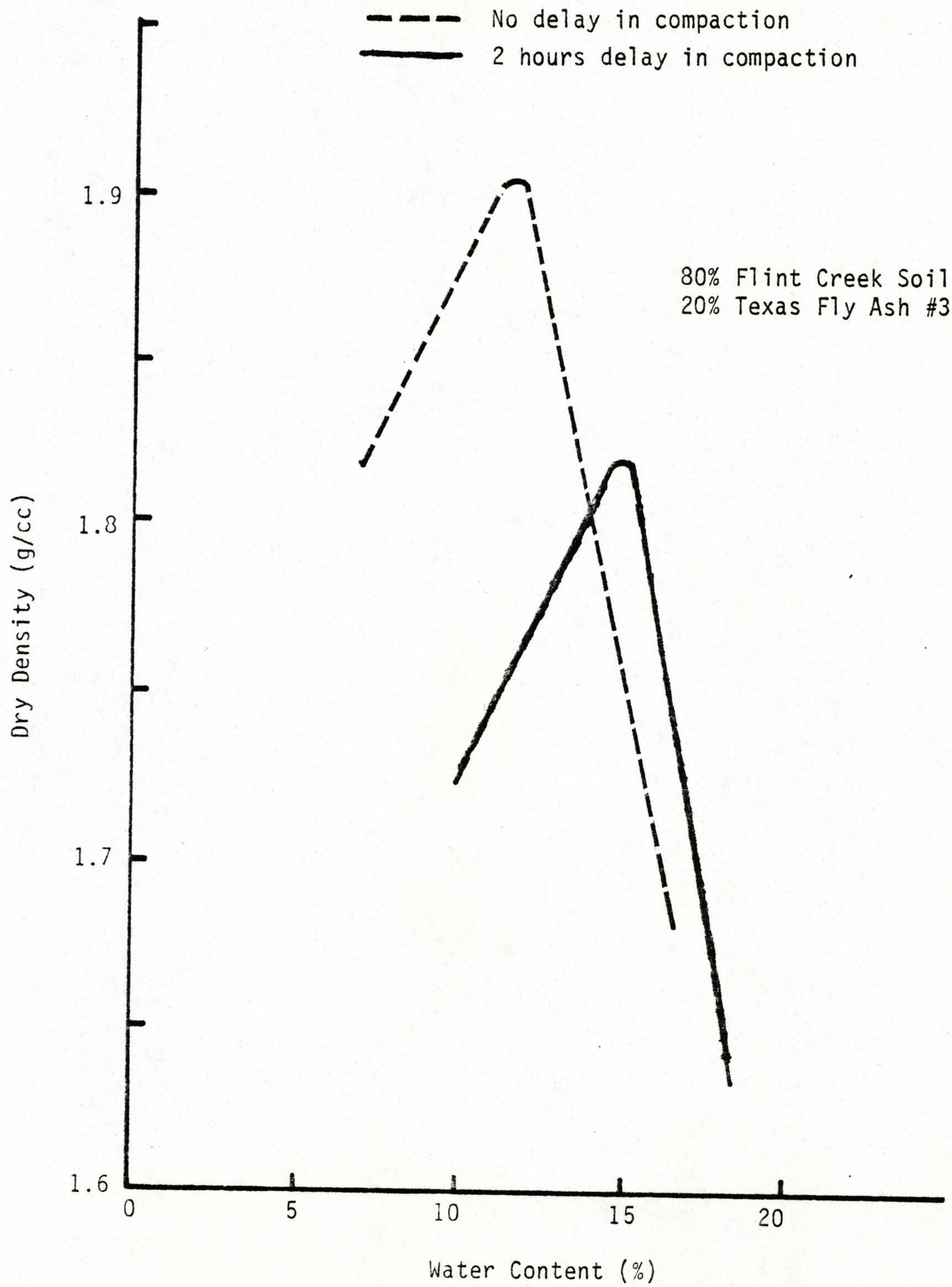


Figure 15. Relationship of dry density vs. water content for Flint Creek soil-fly ash mixtures which were compacted by Modified Proctor compactive effort with no time delay and 2 hours delay in compaction.

Texas fly ash #1 and Texas fly ash #2 were 800 psi, 1800 psi and 1300 psi respectively (Figure 16).

2. The maximum 7-day compressive strength of Flint Creek soil with no additive was 60 psi (Figure 14b).

3. For Flint Creek soil-Texas fly ash #3 mixtures compacted immediately after mixing, the maximum 7-day compressive strength was 390 psi, a great improvement over the strength, 60 psi, of Flint Creek soil without fly ash (Figure 17).

Effect of Delayed Compaction

Delayed compaction of soil-fly ash mixtures effects the moisture density relation and unconfined compressive strength. Results are shown in Table 3 for 2 hours delay and Table 7 for different time delays in compaction.

Moisture-Density Relationships:

1. Comparing with no delayed compaction, two hours delay in compaction reduced the maximum dry density of sand-Pueblo fly ash mixtures from 2.10 g/cc to 2.05 g/cc and increased the optimum moisture content from 5.0% to 8.2% (Figures 10 and 18).

2. For sand-Texas fly ash #1 mixtures, two hours delay in compaction decreased the maximum dry density to 2.01 g/cc and increased the optimum moisture content to 8.2% (Figures 11 and 18).

3. The maximum dry density of sand-Texas fly ash #2 mixtures increased to 2.14 g/cc and the optimum moisture content increased to 5.5% due to 2 hours delay in compaction (Figures 12 and 18).

4. Mixtures with different ratios of fly ash to Flint Creek soil were subjected to the 2 hours delayed compaction test. The results of

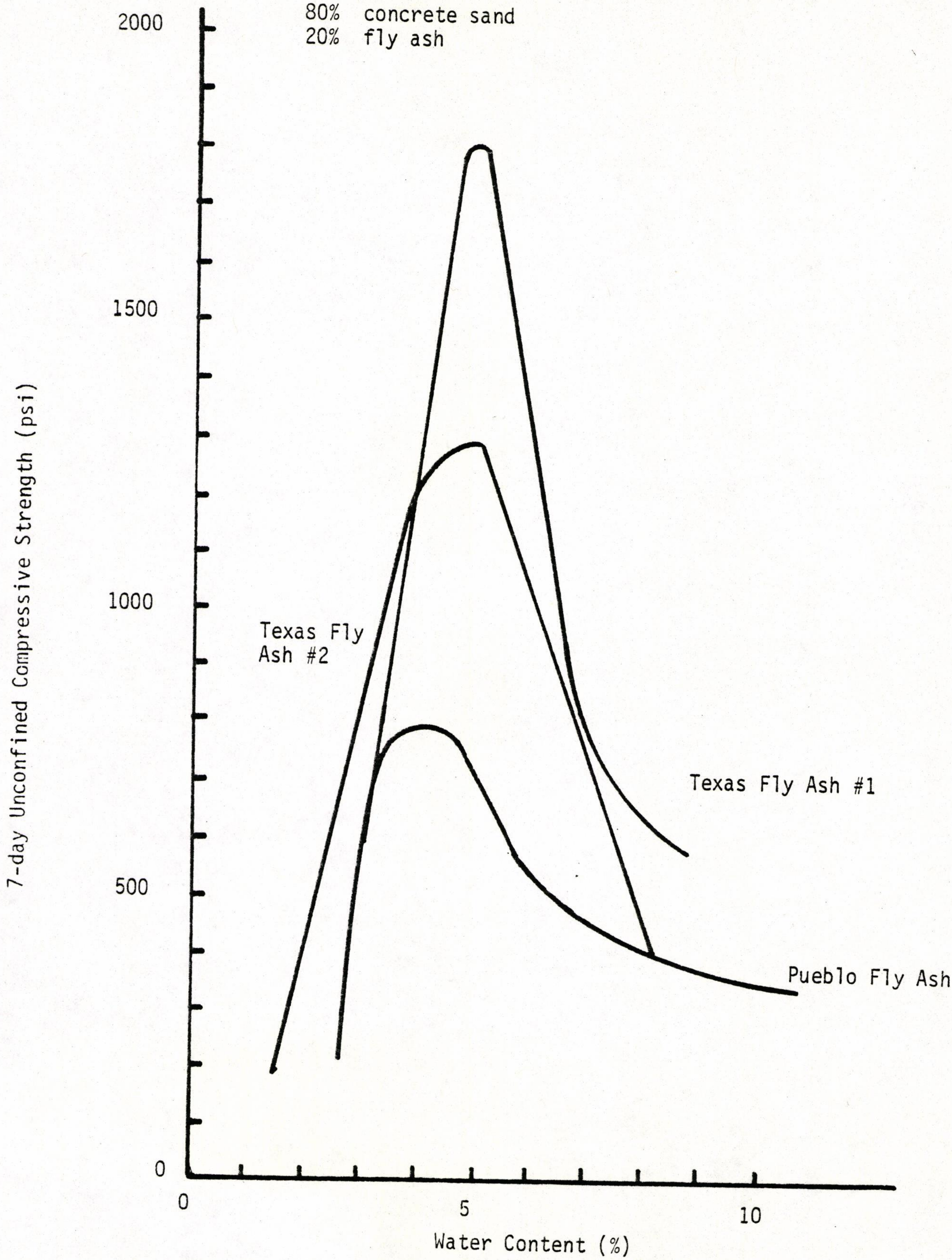


Fig-16 Relationships of compressive strength vs. water content for sand-fly ash mixtures which were compacted by Modified Proctor effort without time delay.

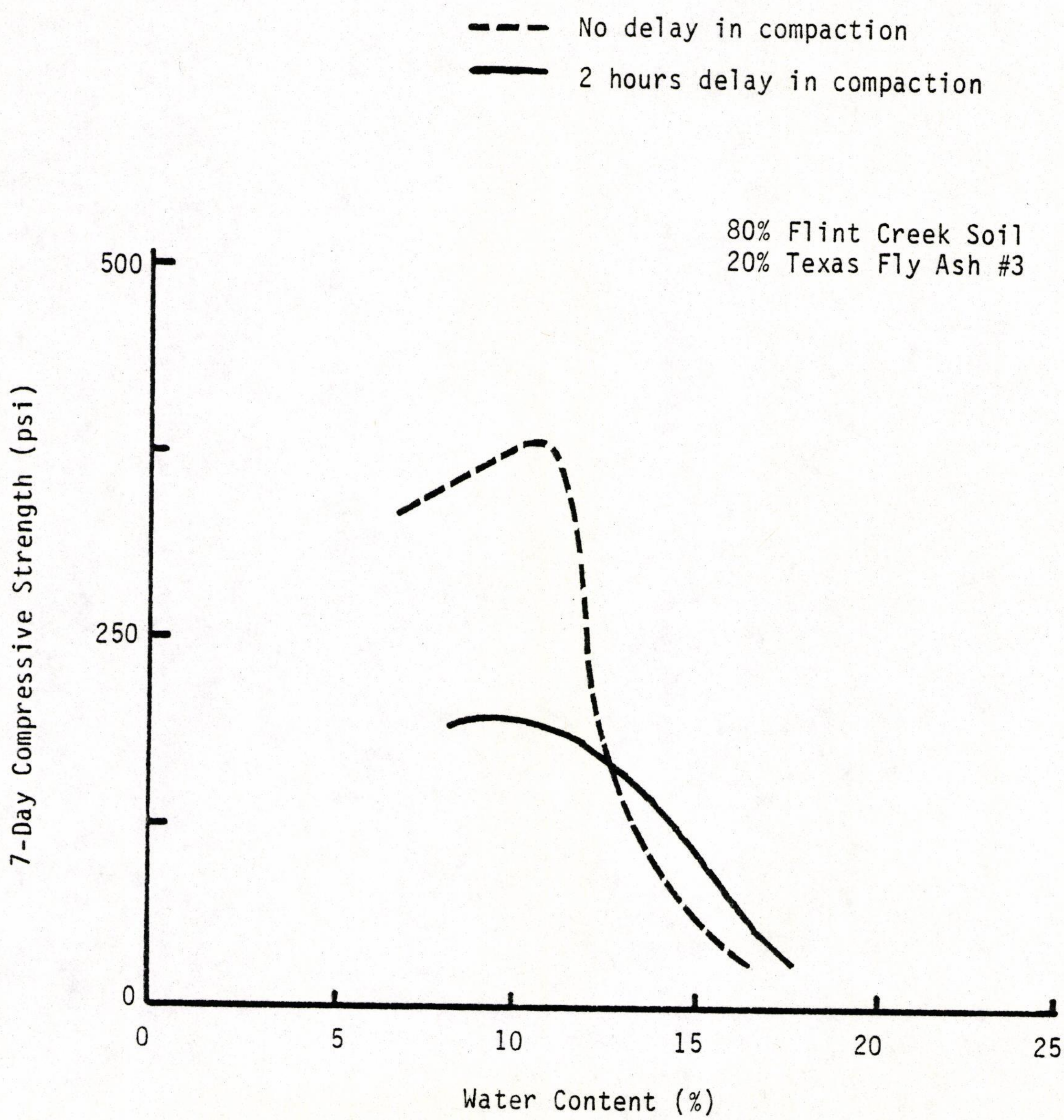


Figure 17. Relationship of compressive strength vs. water content for Flint Creek soil-fly ash mixtures which were compacted by Modified Proctor compactive effort with no time delay and 2 hours delay in compaction.

TABLE 7. Compressive strength, optimum moisture content and maximum dry density of various sand-fly ash mixtures which were compacted with different time delay

	No Delay Compaction	1 Hr. Delay Compaction	2 Hrs. Delay Compaction	3 Hrs. Delay Compaction	4 Hrs. Delay Compaction
* 80% sand + 20% Pueble fly ash					
Optimum moisture content (%)	5	-	8.2	-	-
Maximum dry density (2/c.c)	2.07	2.0	1.98	1.95	1.93
Compressive strength (psi)	742	643	497	264	102
* 80% sand + 20% Texas fly ash #1					
Optimum Moisture content (%)	5.5	-	8.2	-	8.5
Maximum dry density (g/c.c.)	2.1	-	2.01	-	2.0
Compressive strength (psi)	1800	-	808	-	832
*80% sand + 2-% Texas fly ash #2					
Optimum moisture content (%)	5	5.5	5.5	5.5	5.5
Maximum dry density (g/c.c.)	2.12	2.13	2.14	2.12	2.12
Compressive strength (psi)	1293	1532	1739	1303	1015

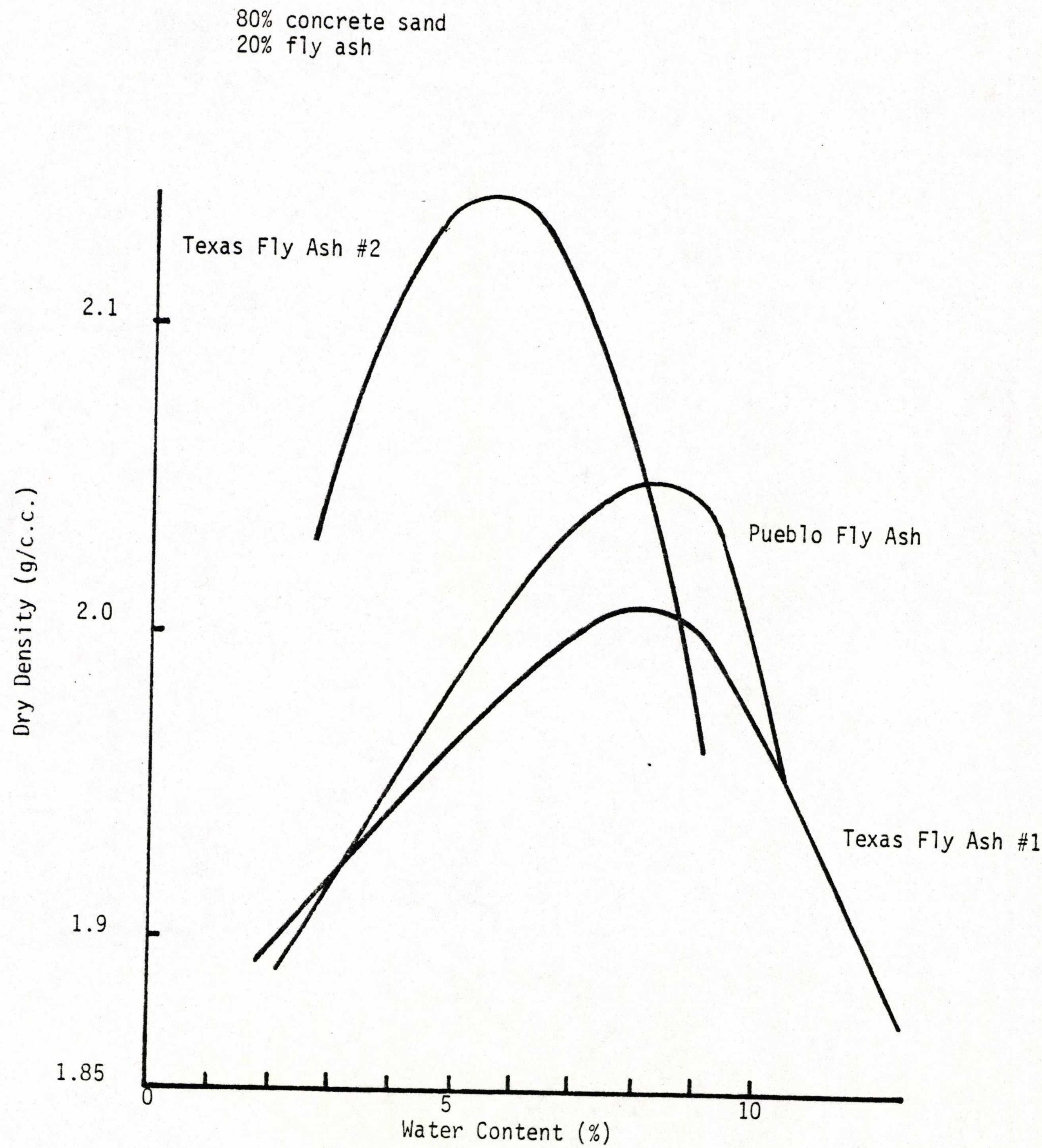


Fig-18 Relationships of dry density vs. water content for sand-fly ash mixtures which were compacted by Modified Proctor effort with 2 hrs. delay after mixing.

moisture-density relationships are shown in Figure 19.

For 90% Flint Creek soil + 10% Texas fly ash #3 mixture, the optimum moisture content and maximum dry density was 11.9% and 1.88 g/cc respectively.

For 80% Flint Creek soil + 20% Texas fly ash #3 mixture, the optimum moisture content was 14.5% and the maximum dry density was 1.82 g/cc.

The mixtures of 70% Flint Creek soil and 30% Texas fly ash #3 had an optimum moisture content of 14.2% and a maximum dry density of 1.80 g/cc.

5. Modified Proctor compaction tests with different time delay were conducted on sand-fly ash mixtures.

For sand-Pueblo fly ash mixtures, the maximum dry density decreased from 2.07 g/cc at no delay to 1.93 g/cc at 4 hour delay. The maximum dry density decreased from 2.1 g/cc at no delay to 2.0 g/cc at 4 hours delay (Figures 20 and 21).

For sand-Texas fly ash #2 mixtures, the optimum moisture content increased from 5% at no delay in compaction to 5.5% at 1 hour delay in compaction and kept on same percentage of moisture for 2 hours, 3 hours, and 4 hours delay. The maximum dry density changed little from 2.2 g/cc at no delay in compaction (Figures 20 and 21).

The results of unconfined compressive strength for stabilized soil with 2 hours delay in compaction are listed in Table 3. Table 7 indicates the results of unconfined compressive strentgh for sand-fly ash mixtures with different time delay in compaction.

1. For sand-Pueblo fly ash mixtures, the maximum 7-day compressive strength decreased from 740 psi at no delay to 100 psi at 4 hours delay (Figure 22).

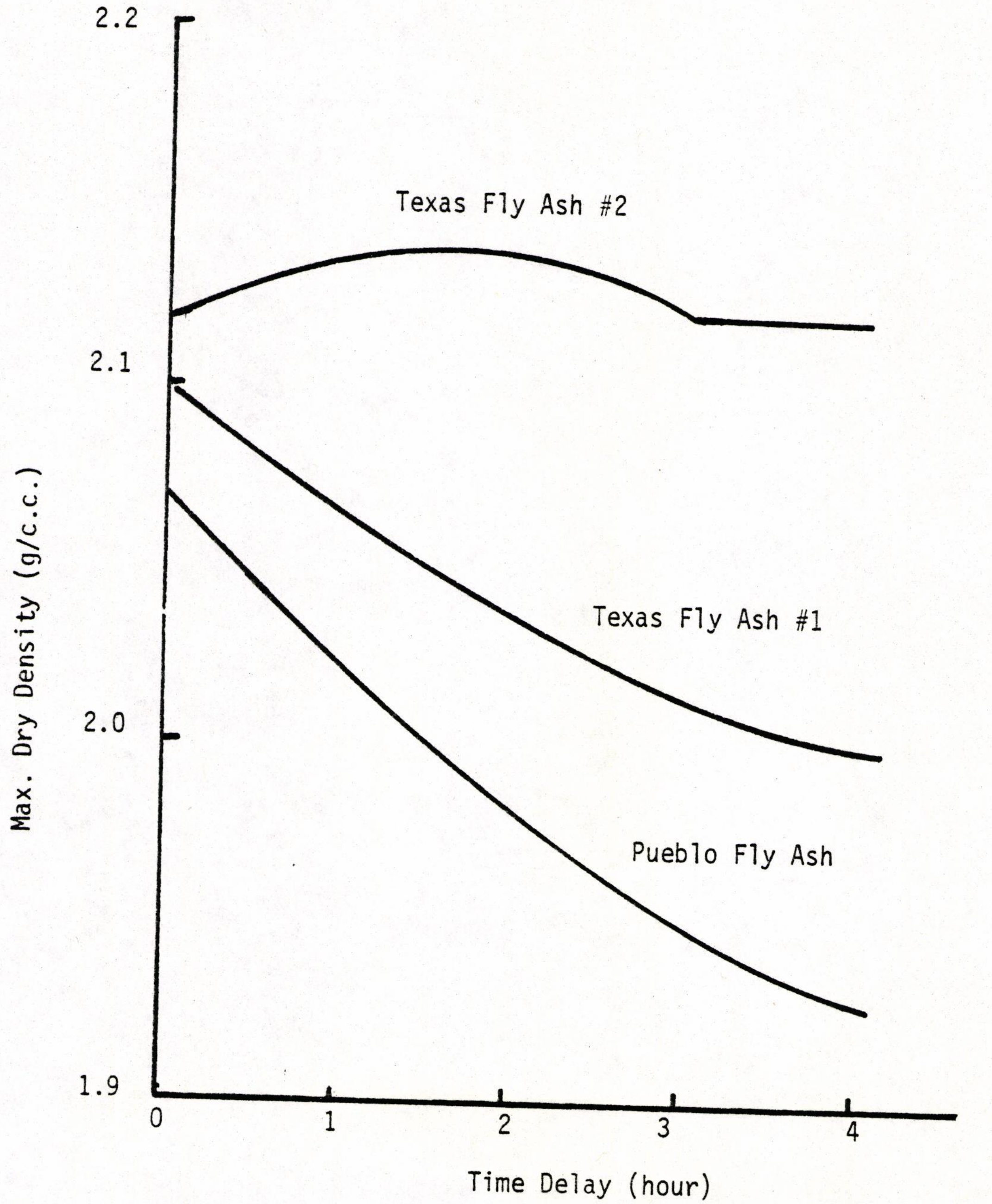


Fig-21 Effect of time delay on maximum dry density for sand-fly ash mixtures which were compacted by Modified Proctor compactive effort.

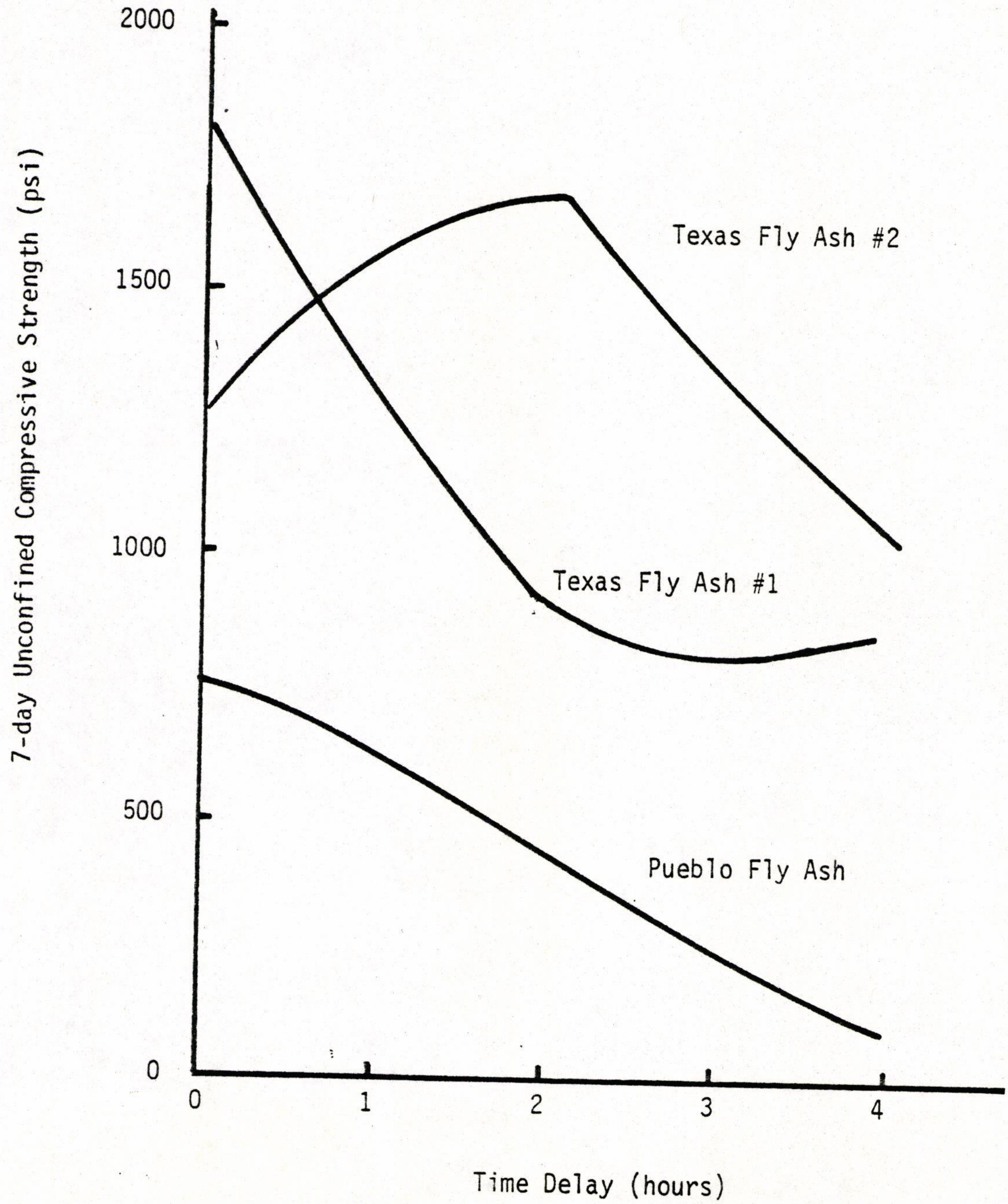


Fig-22 Effect of time delay on compressive strength for sand-fly ash mixtures which were compacted by Modified Proctor compactive effort.

The maximum compressive strength of sand-Texas fly ash #1 mixtures decreased from 1800 psi at no delay to 830 psi at 4 hours delay (Figure 22).

3. For sand-Texas fly ash #2 mixtures, the maximum compressive strength increased as delayed time increased to 2 hours, then decreased at 3 and 4 hours delay (Figure 22).

4. Figure 23 indicates the relations between compressive strength and water content for mixtures of sand-Pueblo fly ash, sand-Texas fly ash #1 and sand-Texas fly ash #2, which were compacted with 2 hours delay after mixing.

5. The compressive strength, with 2 hours delay in compaction, for 90% Flint Creek soil and 10% Texas fly ash #3 was 160 psi (Figure 24).

For 80% Flint Creek soil and 20% Texas fly ash #3, the 2 hours delay compressive strength was 190 psi. 70% Flint Creek soil and 30% Texas fly ash #3 mixtures had a maximum compressive strength of 280 psi.

In the relation of compressive strength vs. moisture content of 80% Flint Creek soil and 20% Texas fly ash #3 mixtures, no peak was found on the curve, the maximum compressive strength was at the point with the lowest moisture content.

Use of Chemical Additive in Soil-Fly Mixtures

Previous studies conducted at the University of Arkansas indicated that TMP (Tri Methlol Propane) and salt could fix the water in some form to improve the delayed compaction characteristics of soil-fly ash mixtures (Figures 25 and 26 compared to Figure 4).

Gypsum, PDA and Protard-77 were mixed with sand-fly ash mixtures to reduce the effect of delayed compaction.

1. One percent (5% in terms of weight of fly ash) was the optimum

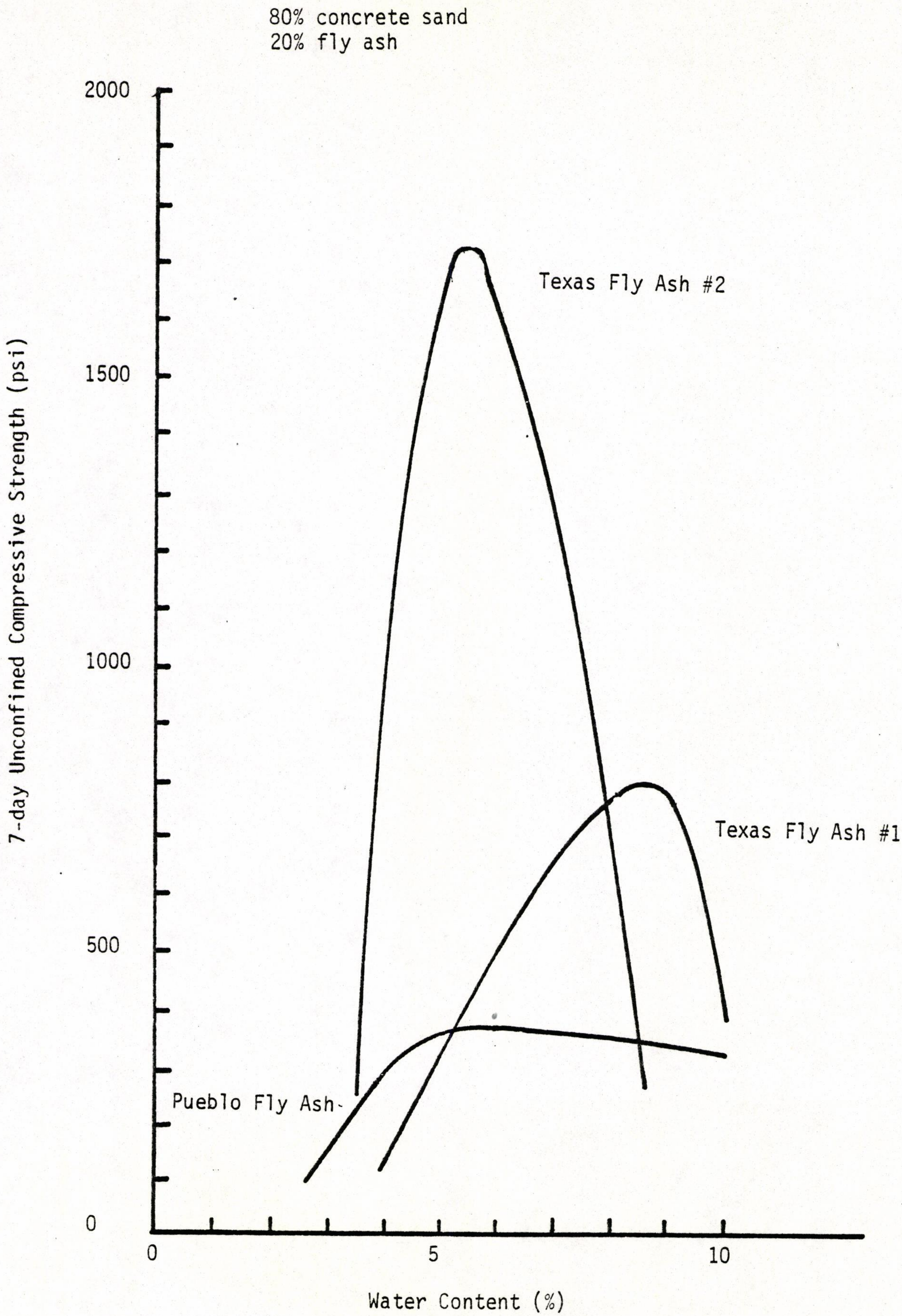


Fig-23 Relationships of compressive strength vs. water content for sand-fly ash mixtures which were compacted by Mod. Proctor effort with 2 hrs. delay after mixing.

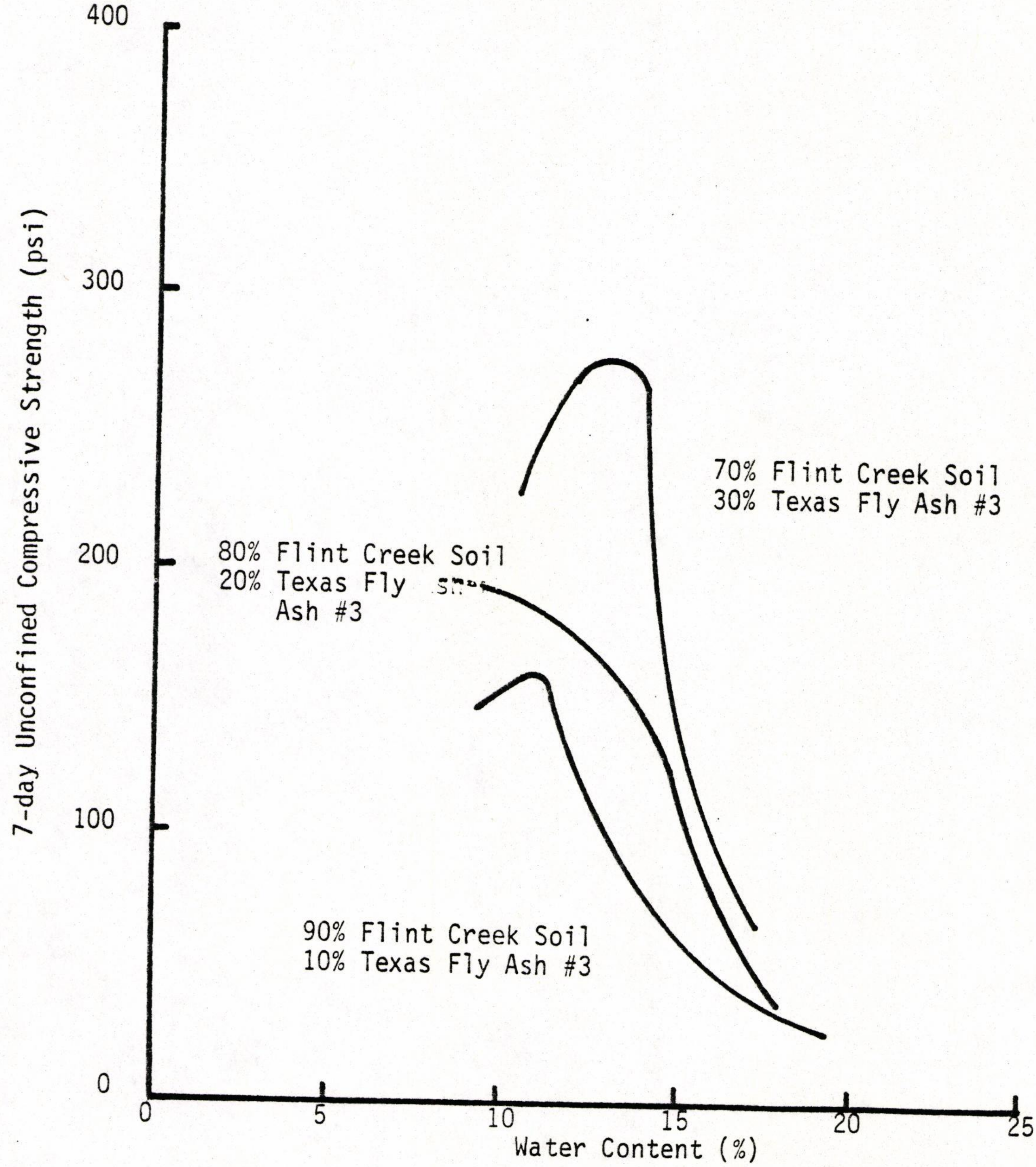


Fig-24 Relationships of compressive strength vs. water content for mixtures with different ratio of Flint Creek soil to fly ash, and compacted with 2 hrs. delay after mixing.

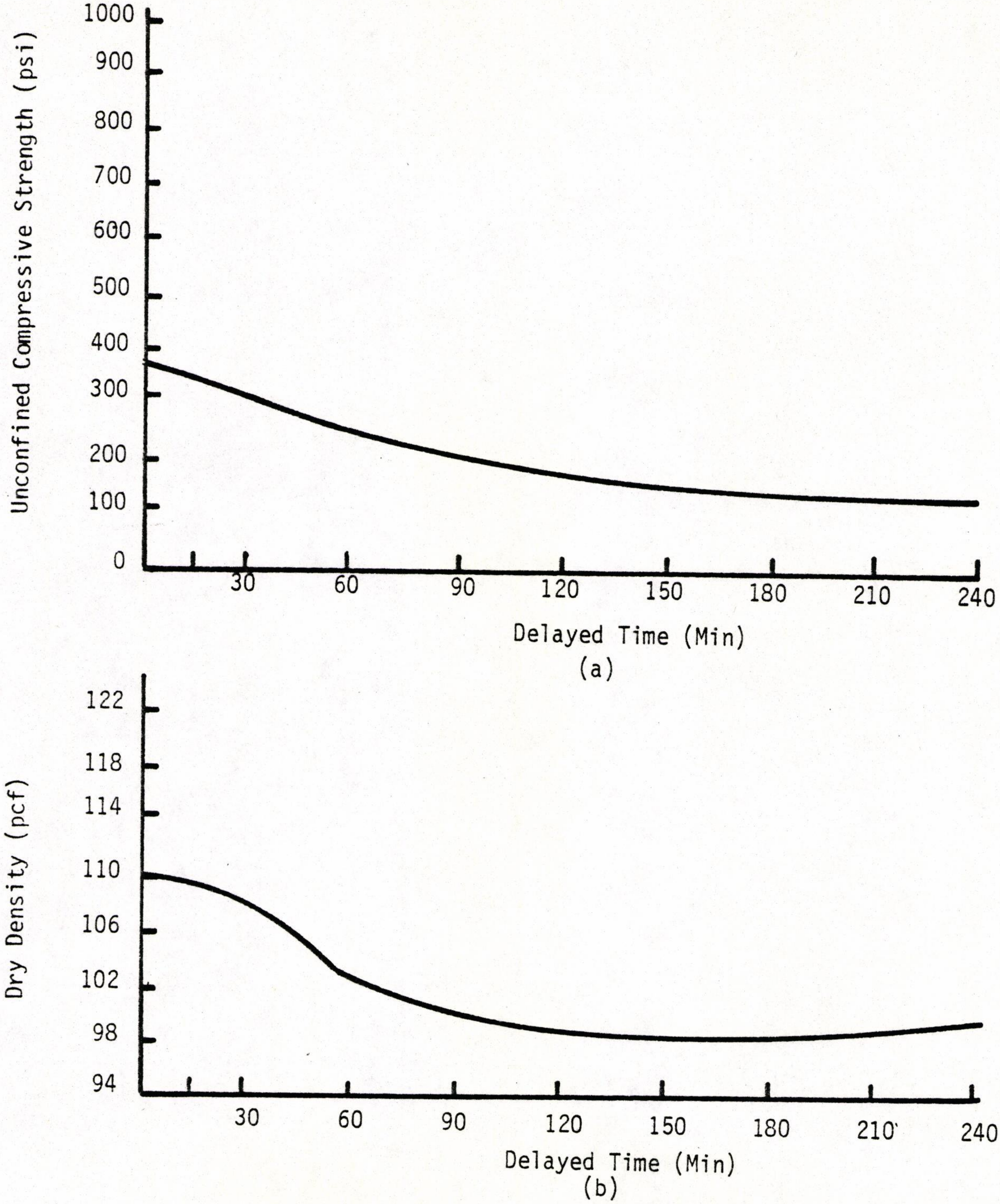


Fig-25 Effect of delay of compaction on 80% sand + 20% fly ash mixture with 0.5% TMP; (a) 7-day unconfined compressive strength vs. delay time, (b) Dry density vs. delay time. (From Thornton and Parker, 1975, p. 66).

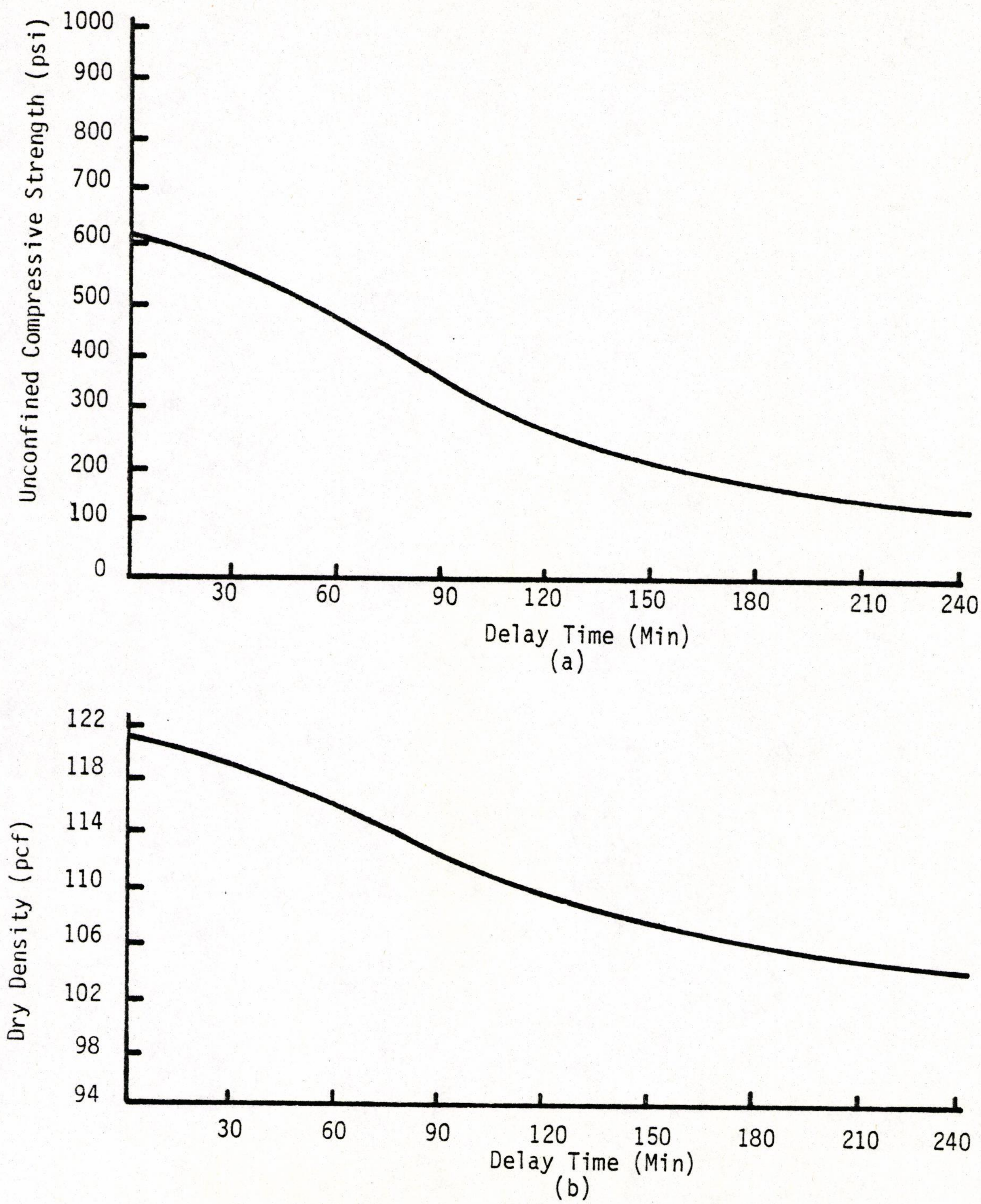


Fig-26 Effect of delay of compaction on 78% sand + 20% fly ash + 2% salt mixture; (a) 7-day unconfined compressive strength vs. delay time, (b) dry density vs. delay time. (From Thornton and Parker, 1975, p. 67

amount of gypsum to be added to the sand-Pueblo fly ash mixture to improve the no delay compressive strength (Figure 27). For 2 hours delayed compaction, 2% gypsum was optimum to improve the delayed compressive strength of sand-Pueblo fly ash mixture (Figure 27).

2. For sand-Pueblo fly ash mixtures, Protard-77 made no improvement in the compressive strength at any time (Figures 28 and 29).

3. Another chemical additive, PDA, was mixed with sand-Pueblo fly ash. No improvement in the compressive strength could be observed in the no delay case. However, a great improvement in the adverse effects of delayed compaction was found (Figures 30 and 31).

4. Gypsum was used as an additive and mixed with sand-Texas fly ash #1 mixture. Gypsum improved the strength and maximum dry density in delayed compaction (Figures 32 and 33).

Effect of Compactive Effort

Different compactive efforts were applied to compact sand-Texas fly ash #1 mixtures (Table 8). The results of using Standard Proctor and Modified Proctor effort to compact sample mixtures with 2 hours delay were separated because a different sand sample was tested. The results of using Standard Proctor effort had an optimum moisture content of 10.5%, a maximum dry density of 1.94 g/cc and a maximum compressive strength of 685 psi. For the Modified Proctor test, the optimum moisture content was 8.2%, the maximum dry density was 2.02 g/cc and the maximum compressive strength was 808 psi.

Fayetteville Clay

So that the effect of fly ash on all types of soil could be seen, a highly plastic clay sample was taken near the University of Arkansas

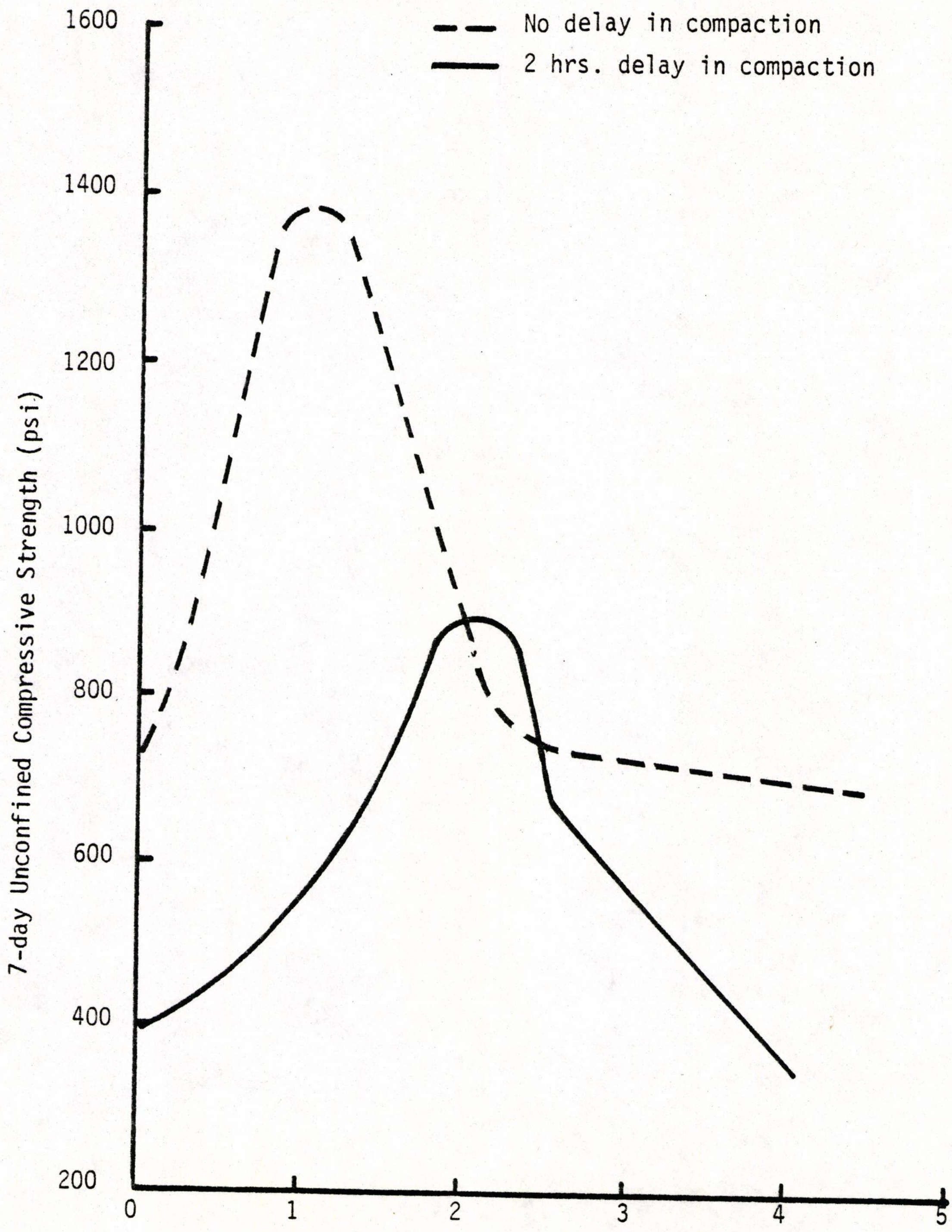


Fig-27 Effect of Gypsum on the compressive strength of 80% sand + 20% Pueblo fly ash mixtures which were compacted without time delay and with 2 hrs. delay after mixing.

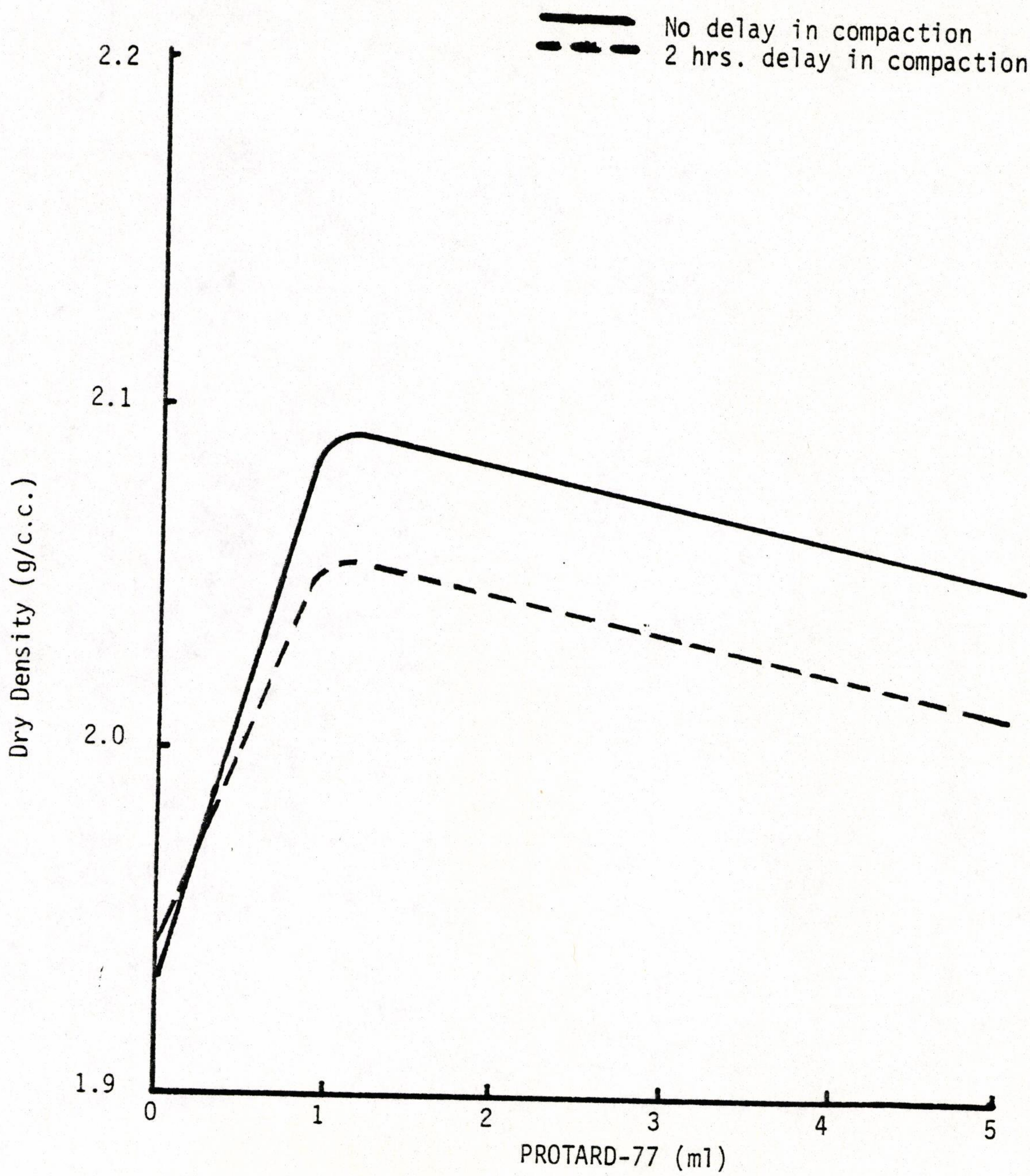


Fig-28 Effect of PROTARD-77 on the dry density of sand-Pueblo fly ash mixtures which were compacted without time delay and with 2 hrs. delay after mixing.

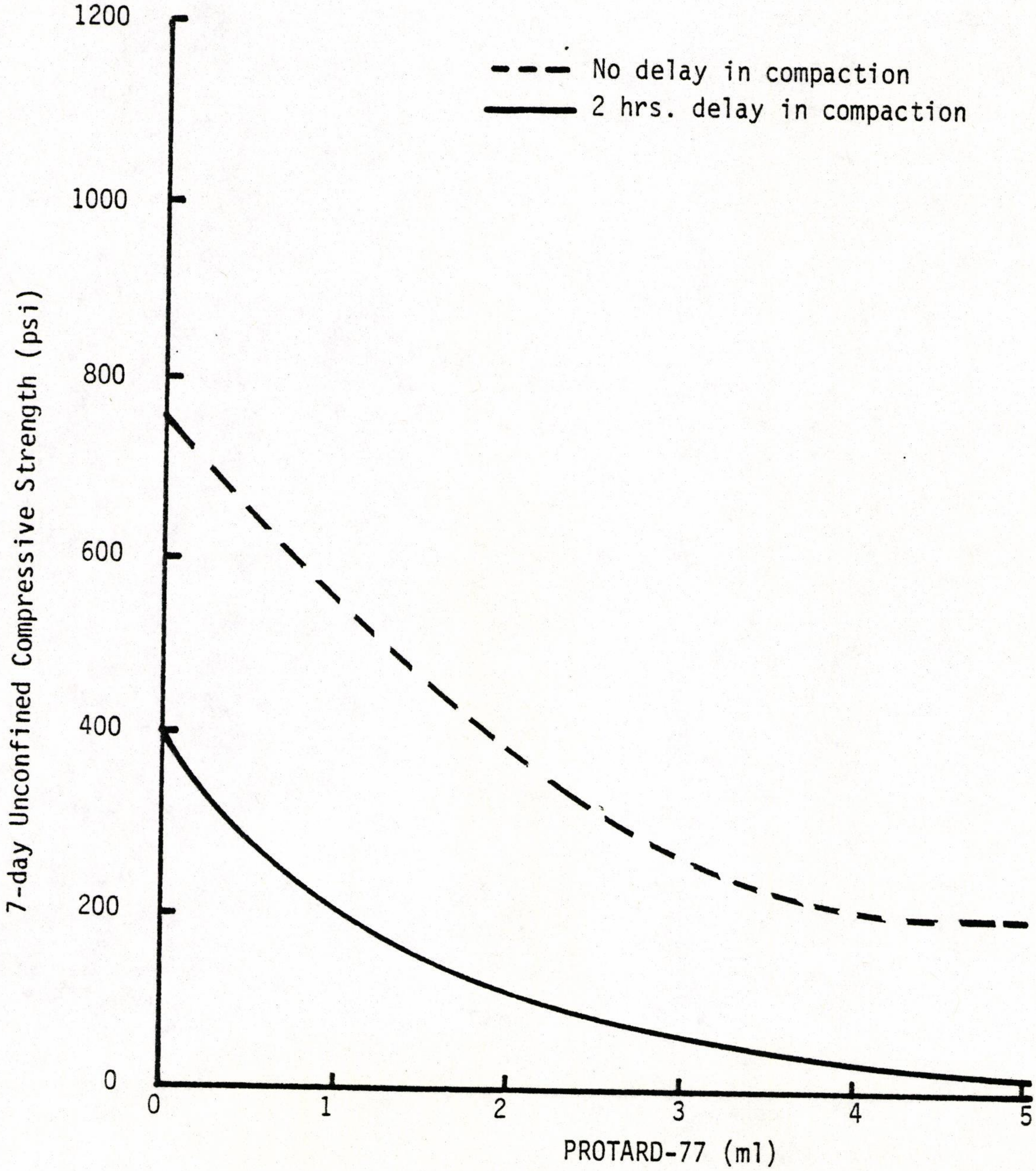


Fig-29 Effect of PROTARD-77 on the compressive strength of sand-Pueblo fly ash mixtures which were compacted without time delay and with 2 hrs. delay after mixing.

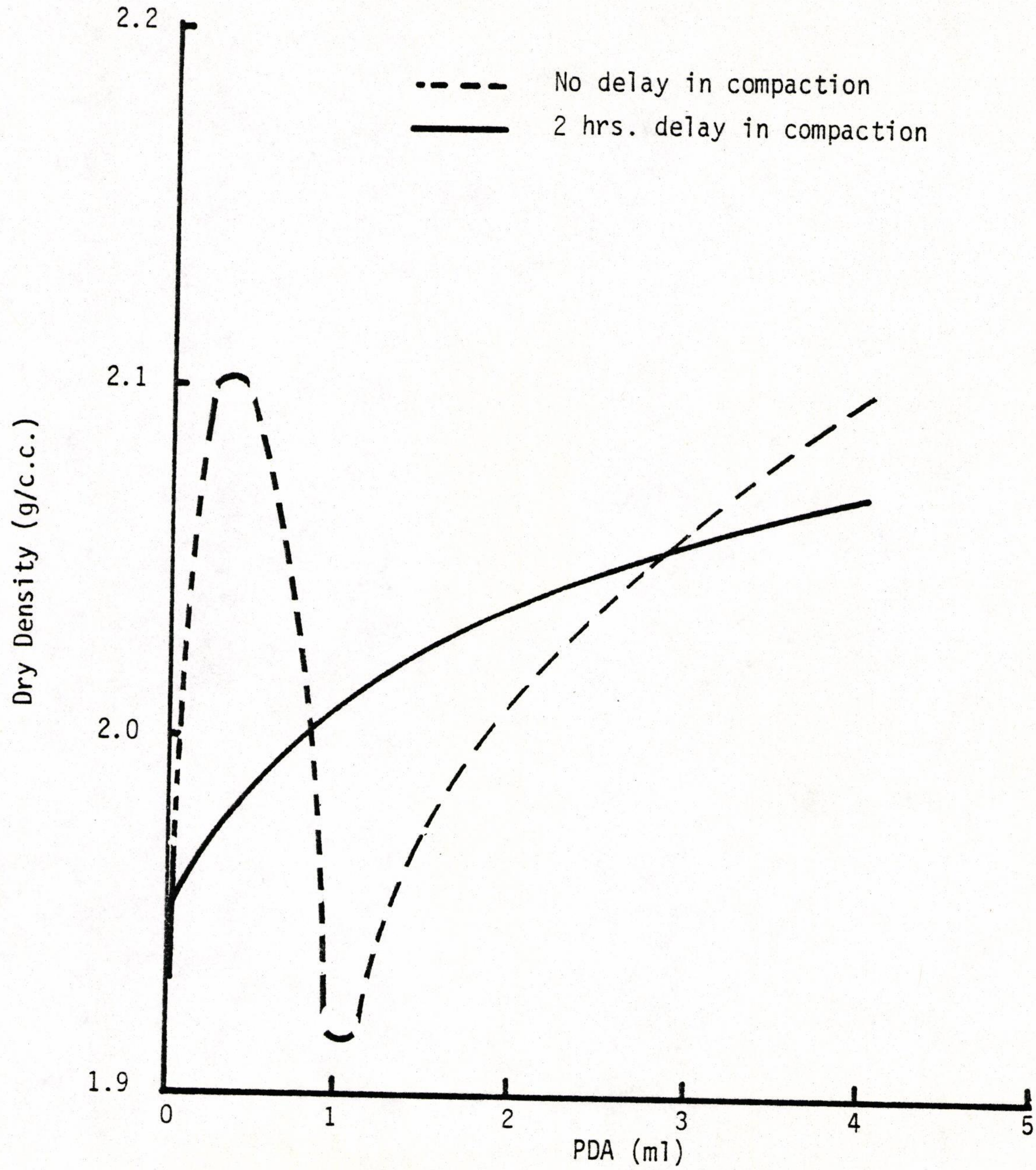


Fig-30 Effect of PDA on the dry density of sand-Pueblo fly ash mixtures which were compacted without time delay and with 2 hrs. delay after mixing.

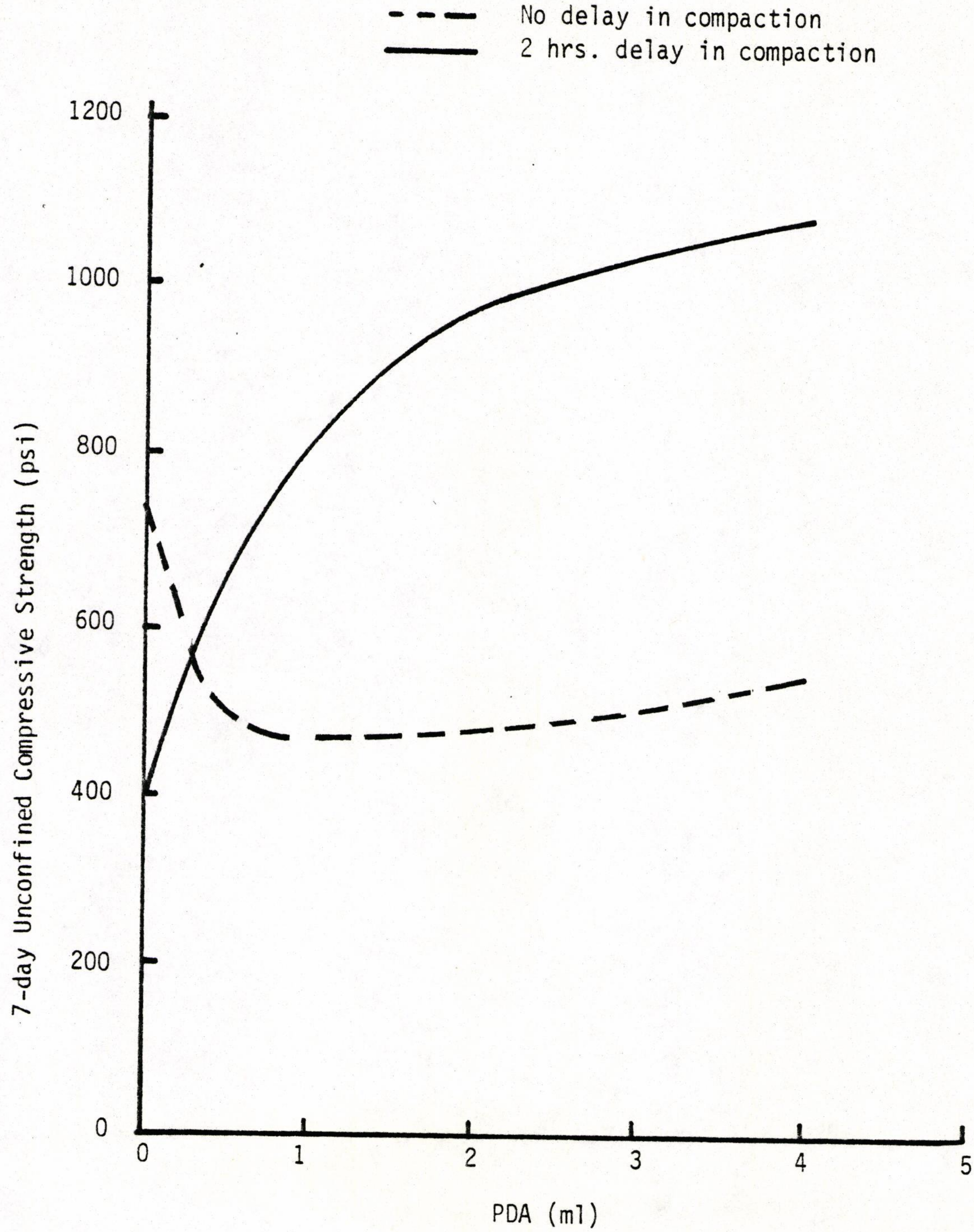


Fig-31 Effect of PDA on compressive strength of sand-Pueblo fly ash mixtures which were compacted without time delay and with 2 hrs. delay after mixing.

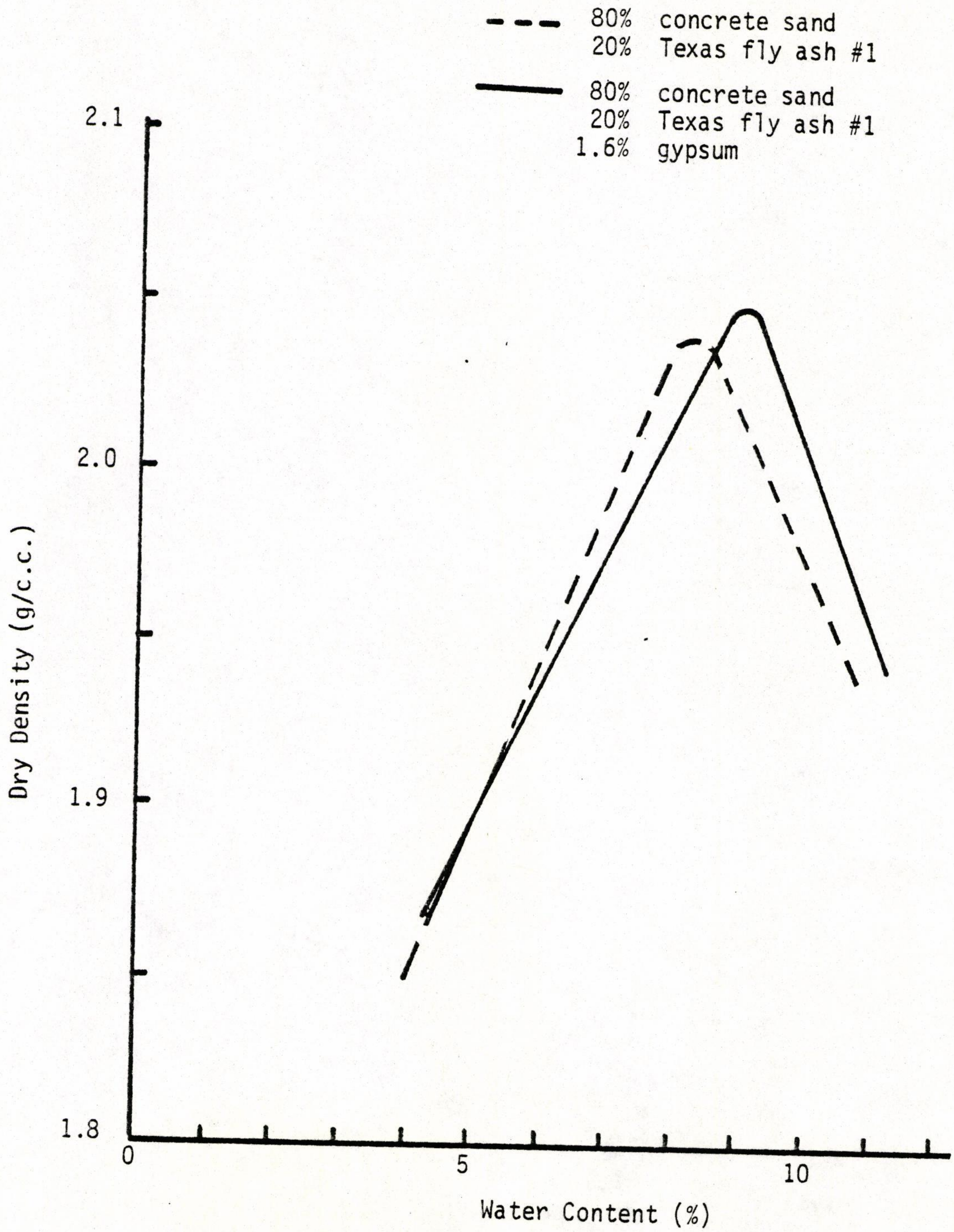


Fig-32 Relationships of dry density vs. water content for sand-fly ash mixtures with and without gypsum, and compacted with 2 hrs. delay

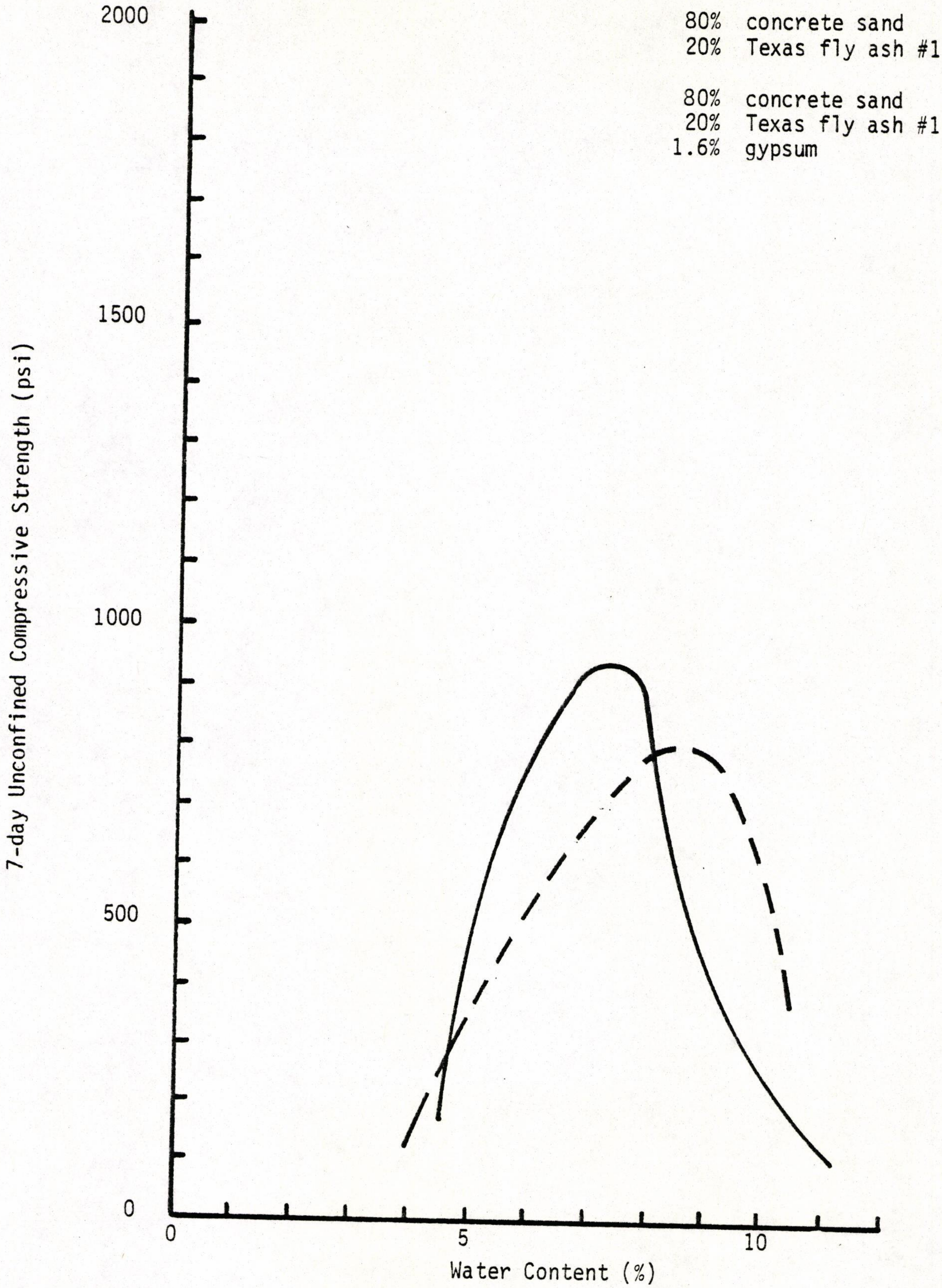


Fig-33 Relationships of compressive strength vs. water content for sand-fly ash mixtures with and without gypsum, and compacted with 2 hrs. delay

Table 8. Effect of Compactive Effort on Mixtures Of

80% Sand and 20% Texas Fly Ash #1 and With 2 hrs. Delay in Compaction

	Standard Proctor Effort (12375 ft-lb/cu. ft)	Modified Proctor Effort (56250 ft-lb/cu ft.)
Optimum Moisture Content (%)	10.5	8.2
Maximum Dry Density (g/c.c.)	1.94	2.02
Max. Compressive Strength (psi)	685	808

on Sunset Street in Fayetteville. The liquid limit of the clay was 133 and plastic index was 97. Specific gravity of soilds of the clay was 2.71. Eighty percent by weight of the soil particles were in the clay size range (less than 0.002 mm).

Fly ash increased the strength of the clay from 190 psi to over 400 psi. Generally, the greater the percent of fly ash, the greater the strength and the lower was the optimum water content. Figures 34 through 37 contain data on the clay-fly ash mixtures.

Flint Creek Test Section

A field test at SWEPCO's Flint Creek power plant fly ash disposal site was conducted in the summer of 1978 to determine the effectiveness of equipment and procedures in soil-fly ash construction.

Lab Results

The fly ashes tested were produced at SWEPCO's power plants at Casion, Texas and at Flint Creek, Arkansas. Grain size curves for the fly ashes are presented in Figures 8 and 38. Chemical analysis for the two fly ashes are presented in Tables 5 and 9.

Proctor and strength data for Flint Creek soil-Texas fly ash mixtures with and without time delay are presented in Figures 15, 17, 19, and 24. With 20% fly ash, the optimum density was 1.91 with no delay and decreased to 1.82 with two hour delay (Figure 15). Unconfined compressive strength was 390 psi with no delay and decreased to 210 psi with 2 hour delay (Figure 17) optimum moisture content was 10% without delay and increased to 14.5% with 2 hour delay. The density of mixtures decreased and the strength increased with increasing fly ash percentages used (Figures 19 and 24).

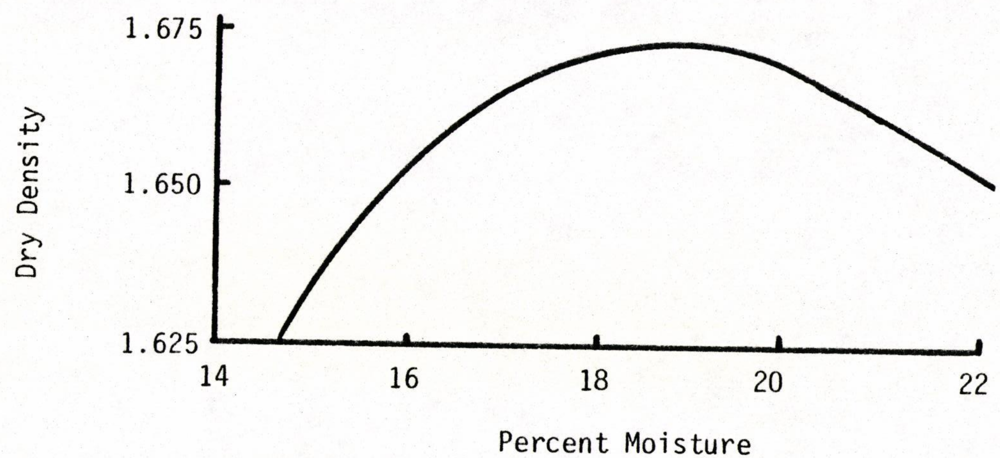


Figure 34. Modified Proctor Test, Fayetteville Clay.

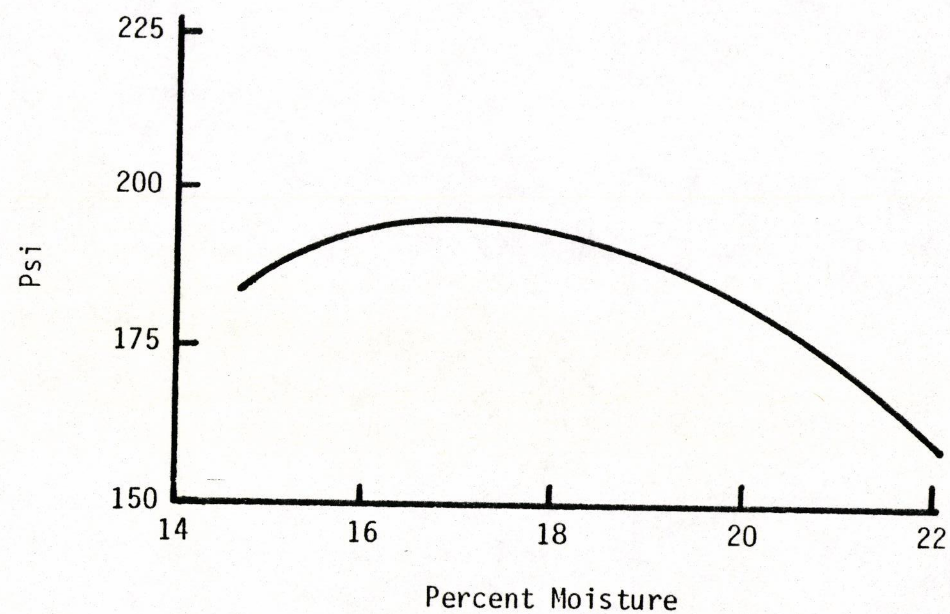


Figure 35. Fayetteville Clay, Strength

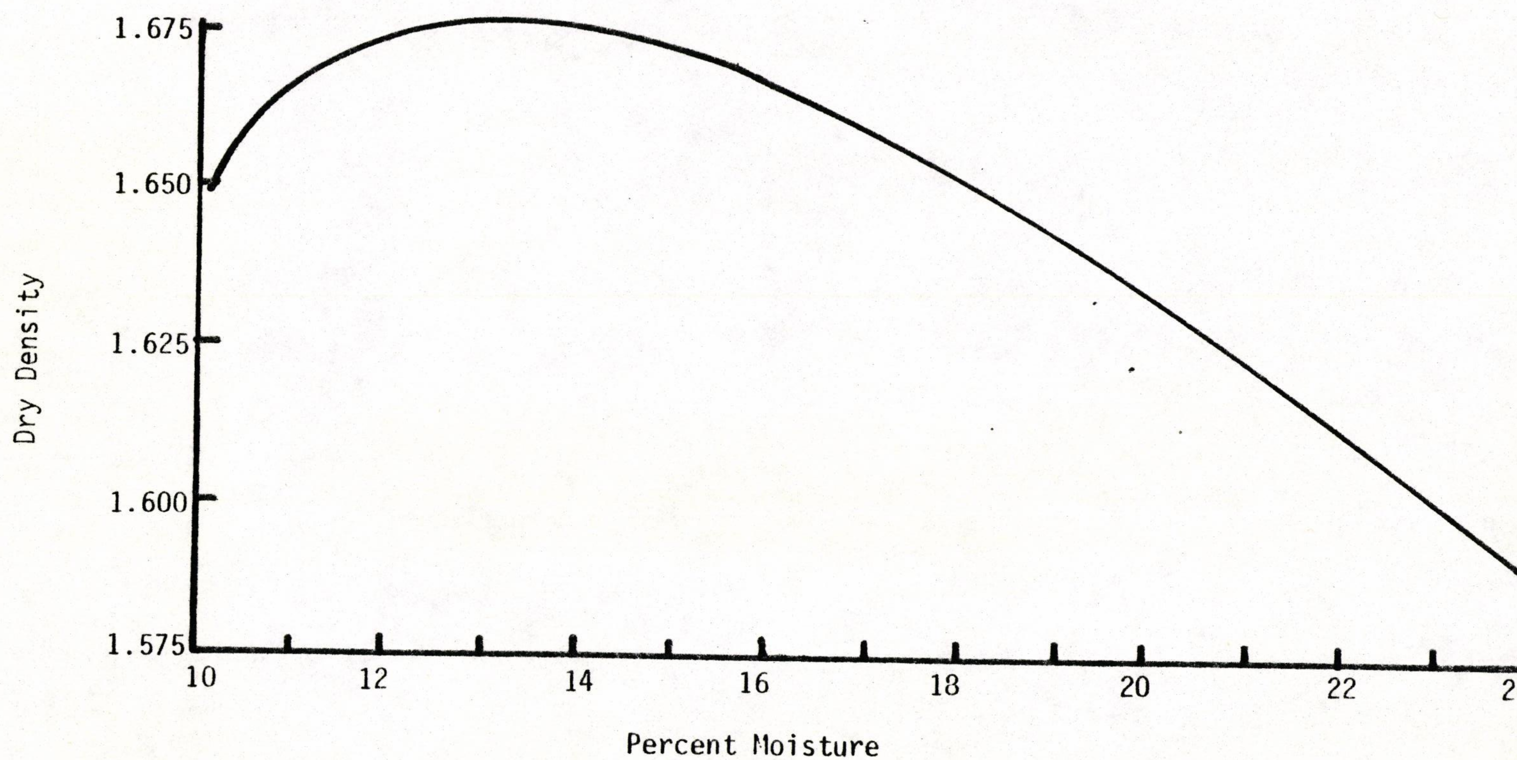


Figure 36. Modified Proctor Test, 80% Fayetteville Clay, 20% Flint Creek Fly Ash No. 2 - No Delay

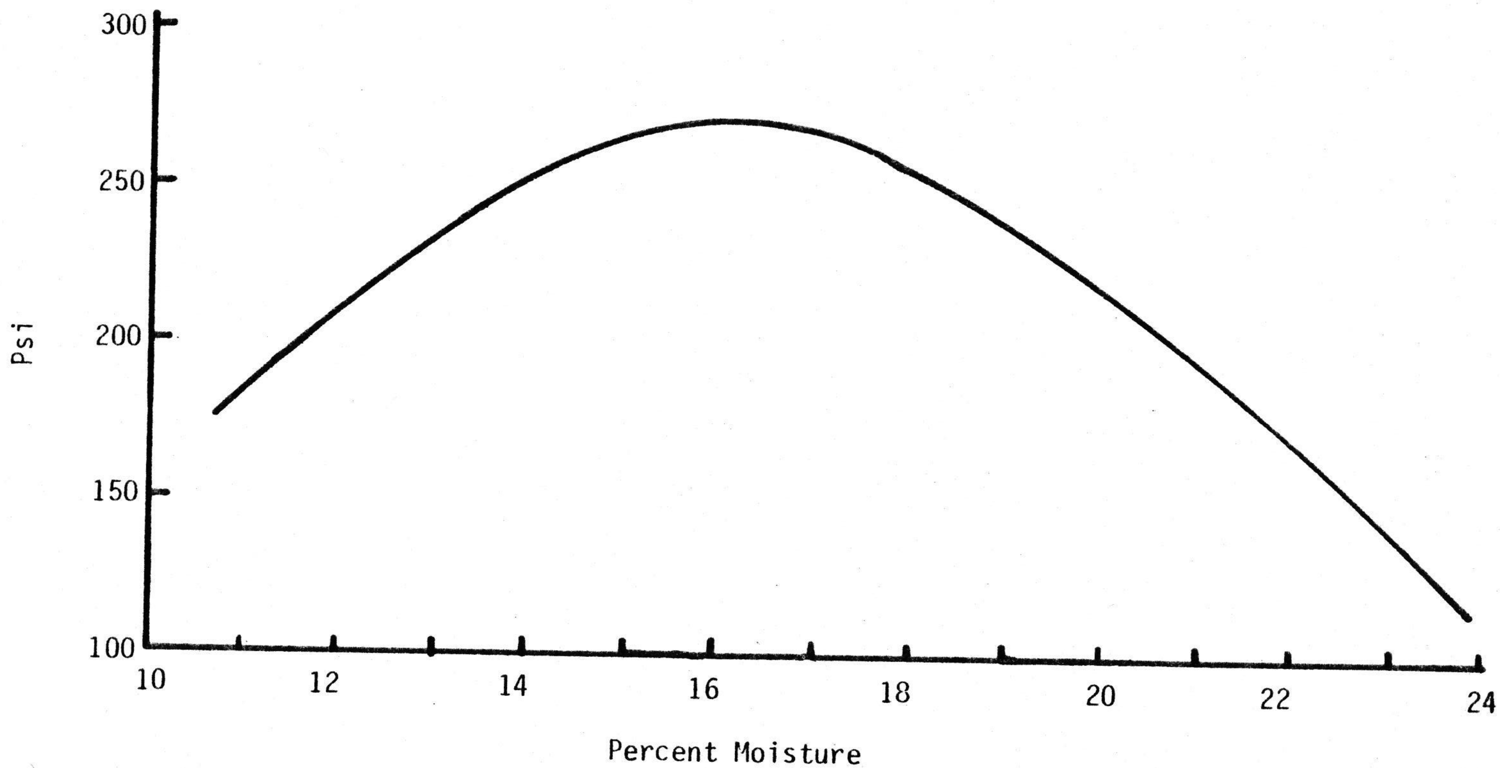


Figure 37. 7 Days Strength, 80% Fayetteville Clay, 20% Flint Creek Fly Ash No. 2 - No delay.

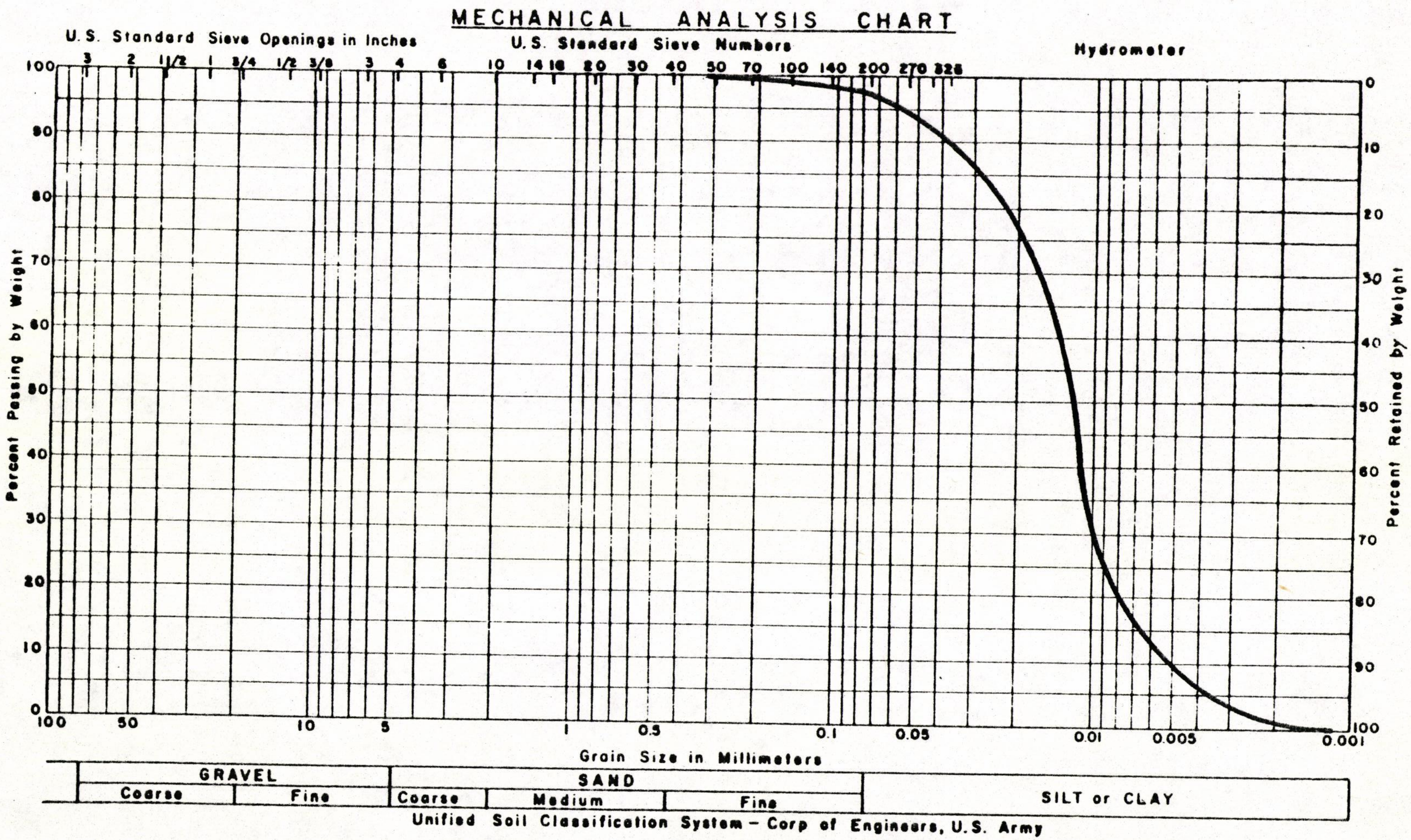


Figure 38. Flint Creek Fly Ash #2

Table 9. Mineral Analysis of Flint Creek Ash

Silicon Dioxide, SiO_2	33.05%
Iron Oxide, Fe_2O_3	5.14%
Aluminum Oxide, Al_2O_3	18.49%
Calcium Oxide, CaO	25.86%
Magnesium Oxide, MgO	3.85%
Sulfur Trioxide, SO_3	2.26%
Sodium Oxide, Na_2O	1.85%
Potassium Oxide, K_2O	0.34%
Titanium Dioxide, TiO_2	2.95%
Loss on Ignition	0.46%

Proctor and strength data for Flint Creek soil-Flint Creek fly ash is presented in Figures 39 and 40. The optimum strength with 20% fly ash and no delay is 450 psi, which is similar to the previously tested Texas fly ash mixtures.

The Field Test

The field test section was constructed on July 26-27, 1978. Three test strips were made, each 250 feet long by 12 feet wide (Figure 41). The strips each contained a given percent fly ash: 10%, 20%, or 30%. Each strip was divided into three sections in order to test the compaction at different water contents. The three sections were made at optimum water content, 2% below optimum and 4% below optimum.

The sequence of construction was as follows:

1. Two to three inches of topsoil and grass were removed with a motor grader.
2. Water, in addition to the natural soil moisture, was added by spraying from a water truck.
3. Fly ash was applied to the strips with a truck-mounted chemical spreader.
4. Mixing was done with one pass of a 7.5 foot width tractor-mounted travel mixer (Pulver type) set at 6 inches depth.
5. Compaction was done with a 15,000 lb. rubber tired roller (Kneomatic).
6. A thin coat of "prime oil" was applied to prevent evaporation.

Figure 42 through 45 are photographs of the construction sequence.

Densities of the compacted soil-fly ash mixtures ranged between 1.52 and 1.63 (95 pcf and 102 pcf). Table 10 gives the densities

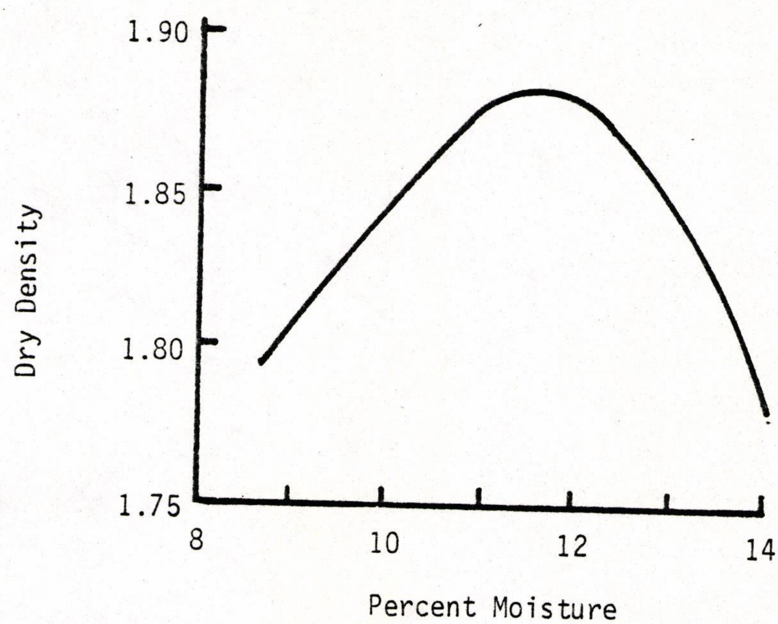


Figure 39. Modified Proctor Test, 80% Flint Creek Soil, 20% Flint Creek Fly Ash No. 2 - No Delay

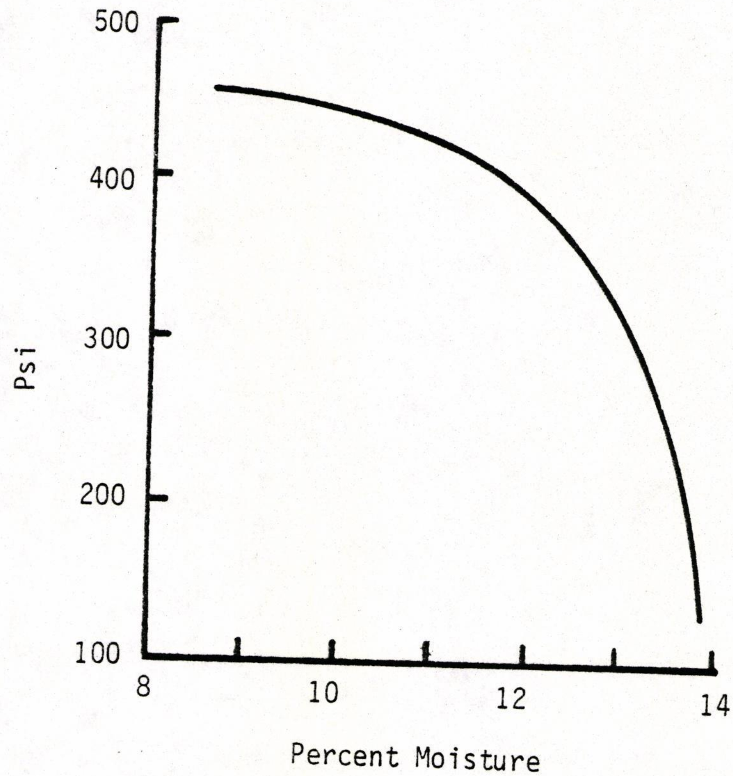


Figure 40. 7 Days Strength, 80% Flint Creek Soil, 20% Flint Creek Fly Ash No. 2 - No Delay

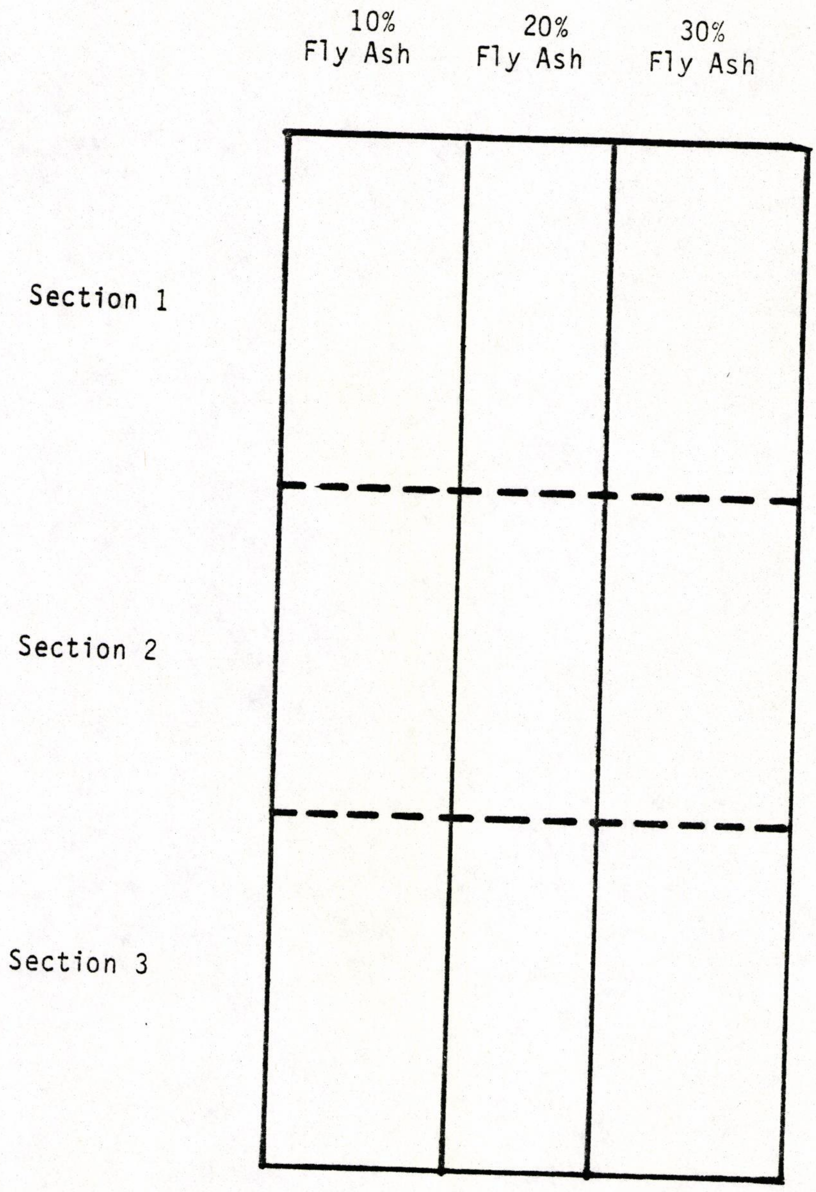


Figure 41. Flint Creek Field Test Section

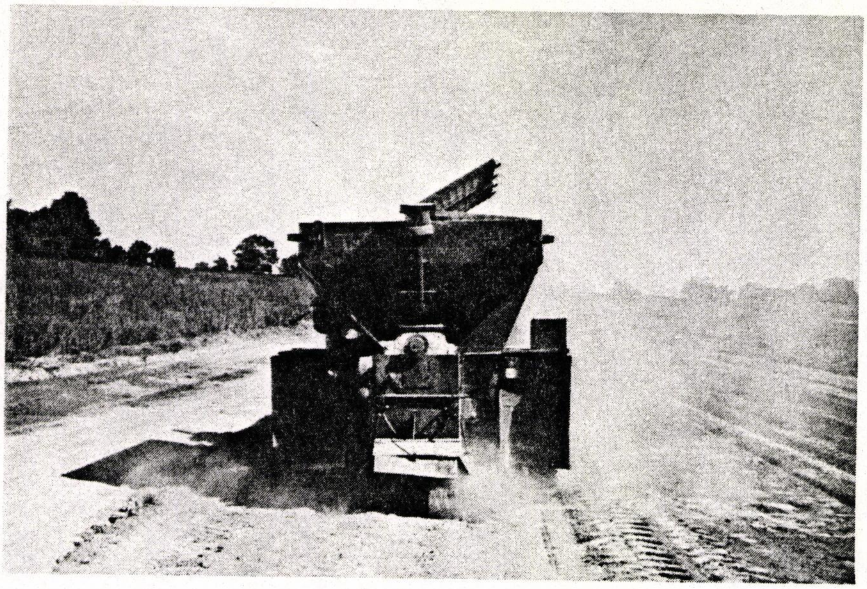


Figure 42

Spreading Fly Ash on Test Section

Figure 43

Mixing Fly Ash and Soil

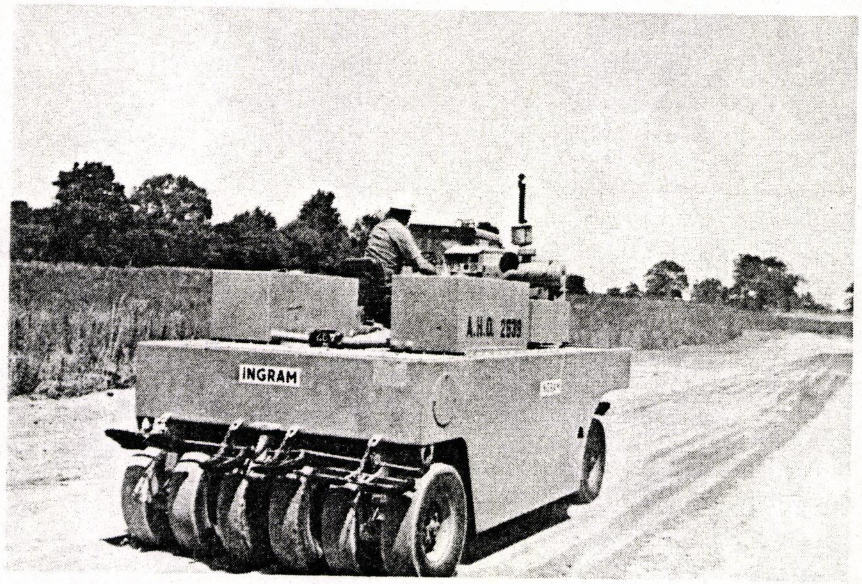


Figure 44

Compacting
Fly Ash-Soil
Mixtures

Figure 45

Sealing
Compaction
Fly Ash
Stabilizer Soil

Table 10. Densities of the Test Sections

	10% Fly Ash	20% Fly Ash	30% Fly Ash
Section 1	1.62 (101 pcf)	1.59 (99 pcf)	1.57 (98 pcf)
Section 2	1.61 (100 pcf)	1.62 (101 pcf)	1.54 (96 pcf)
Section 3	1.63 (102 pcf)	1.52 (95 pcf)	1.52 (95 pcf)

Table 11. Water Contents of the Test Sections

	10% Fly Ash	20% Fly Ash	30% Fly Ash
Section 1	10.5%	9.9%	8.1%
Section 2	10.9%	8.2%	7.8%
Section 3	9.4%	6.8%	5.5%

attained by the roller as measured by a nuclear density device.

The water contents actually achieved in the field varied by as much as 2% from that sought (Table 11). As a result, one section (Section 2 of the 10% fly ash strip) had more moisture than the previous section. From a practical view, there was no difference between Section 1 and Section 2 of the 10% fly ash and 30% fly ash strips.

Return trips were made to the test site to obtain samples and test results at intervals of one week for 4 weeks. Undisturbed samples were difficult to obtain. Shelby tube samples were taken by forcing a thin-walled tube into the sections with a hydraulic jack reacted against a 10 ton truck. The test sections often had enough strength to lift the front end of a half-ton pickup truck (front wheel weight of 2200 lbs.).

The sampling program was not entirely satisfactory because the samples were disturbed (crumbly) when they were removed from the Shelby tubes. The samples, however, did show that field mixing was inadequate. Many samples had layers of unmixed fly ash and most samples were mixed to a depth of only 4 to 5 inches.

A later attempt (2 months) was made to obtain "undisturbed" samples with a coring machine, but even these samples degenerated before they were taken. The coring machine was used dry and with water and compressed air as drilling aids.

The inability to obtain undisturbed samples may indicate that unconfined compressive strength was below 200 psi. In a study of soil cement bases in California, Zube et al (1968) found that 200 psi was the minimum strength of samples which could be taken by coring.

Results of strength testing at 28 days for the samples obtained are given in Table 12. Testing in triaxial compression showed the

Table 12

28 Days Results

Flint Creek Test Section

		Fly Ash %		
		10	20	30
Section 1	Water Content %		9.32	5.95
	Density, gm/cl	1.7 wett	1.62	1.65
	Cohesion, psi		3	5.5
	Friction Angle, ^{o}		15^o	13^o
	Pocket Penetrometer, tsf	4.5+	4.5	4.5
Section 2	Water Content %	2.3	8.76	5.88
	Density, gm/cl	1.53	1.56	1.43
	Cohesion, psi	6	7.5	4.5
	Friction Angle, ^{o}	12^o	11^o	7^o
	Pocket Penetrometer, tsf	4.5	4.5+	4.5
Section 3	Water Content %	6.5	10.6	6.81
	Density, gm/cl	1.46	1.58*	1.34
	Cohesion, psi	7	6.5	
	Friction Angle, ^{o}	7^o	7^o	
	Pocket Penetrometer, tsf	4.25	3.75	3.5

*Fly Ash on top only, about 2"

Angle of internal friction & C are only a rough estimate relatively disturbed samples had a cohesion of less than 10 psi and an angle of internal friction between 7 and 15 degrees. The cohesion in-place is probably much higher because pocket penetrometer readings in the holes the samples were taken from almost always exceeded the limits of the pocket penetrometer (4.5+ tons per square foot). Penetrometer readings this high indicate a cohesion of over 4,500 pounds per square foot (31 psi). Figure 46 shows the results of a typical triaxial test. The higher angles of internal friction are associated with the optimum water contents (Section 1).

The low strength found in the field test is due in part to a lack of particle interlock. The Flint Creek soil is primarily silt sized (Figure 9) and the fly ash is silt sized (Figure 38). When combined, the mixture is uniform and has little particle interlock. Figure 47 is a sieve analysis for the 30% fly ash strip, Section 2.

Another reason for low field strength was the low densities attained in the field. Densities ranged between 1.52 and 1.63, as compared to a maximum density (modified Proctor) of 1.87 for a 20% fly ash mixture. Compaction densities, therefore, were only 81% to 87% of maximum density.

In spite of low field strength, the compacted base showed no distress when used as a temporary haul road for heavy loads of fill material.

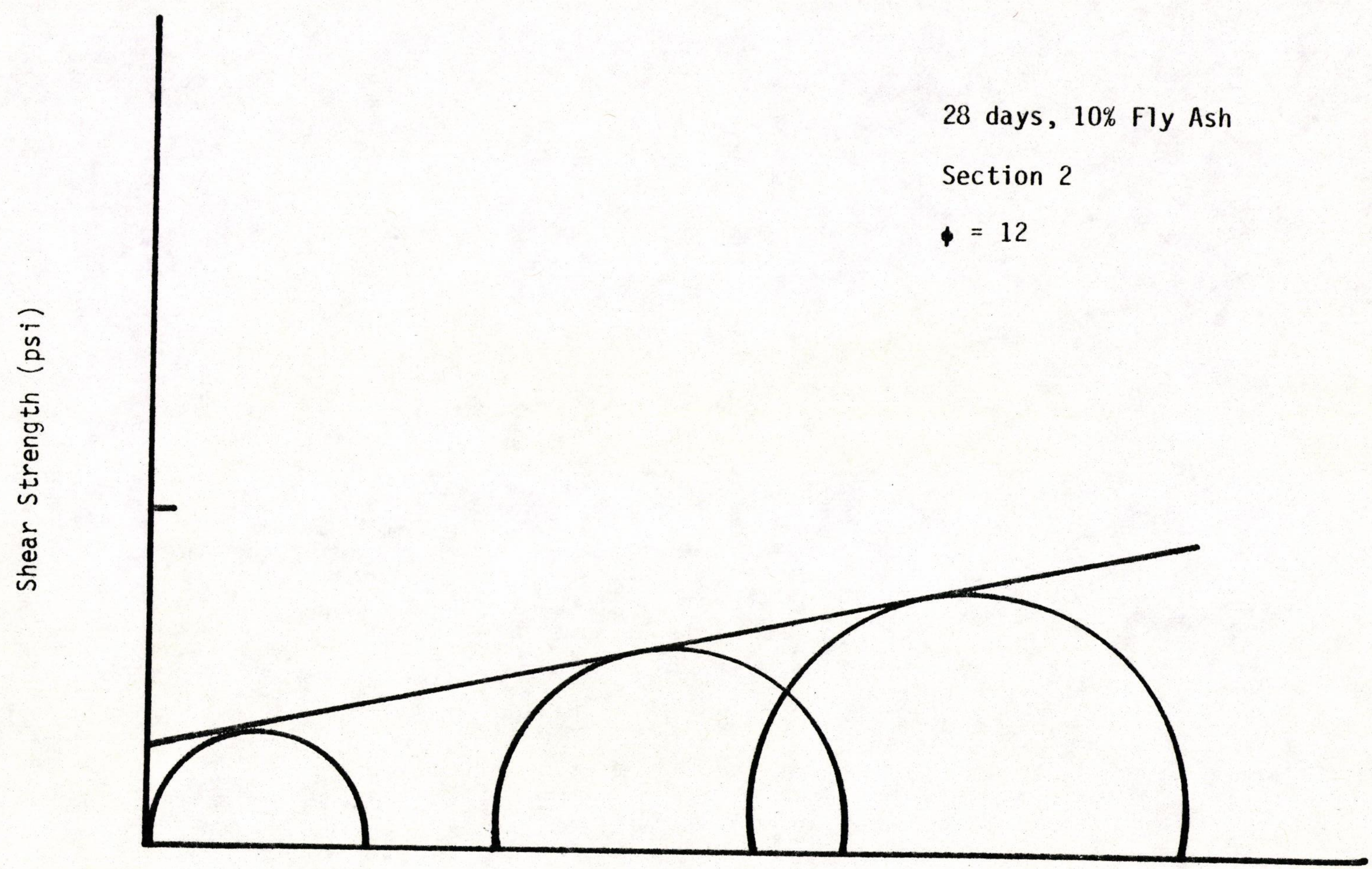
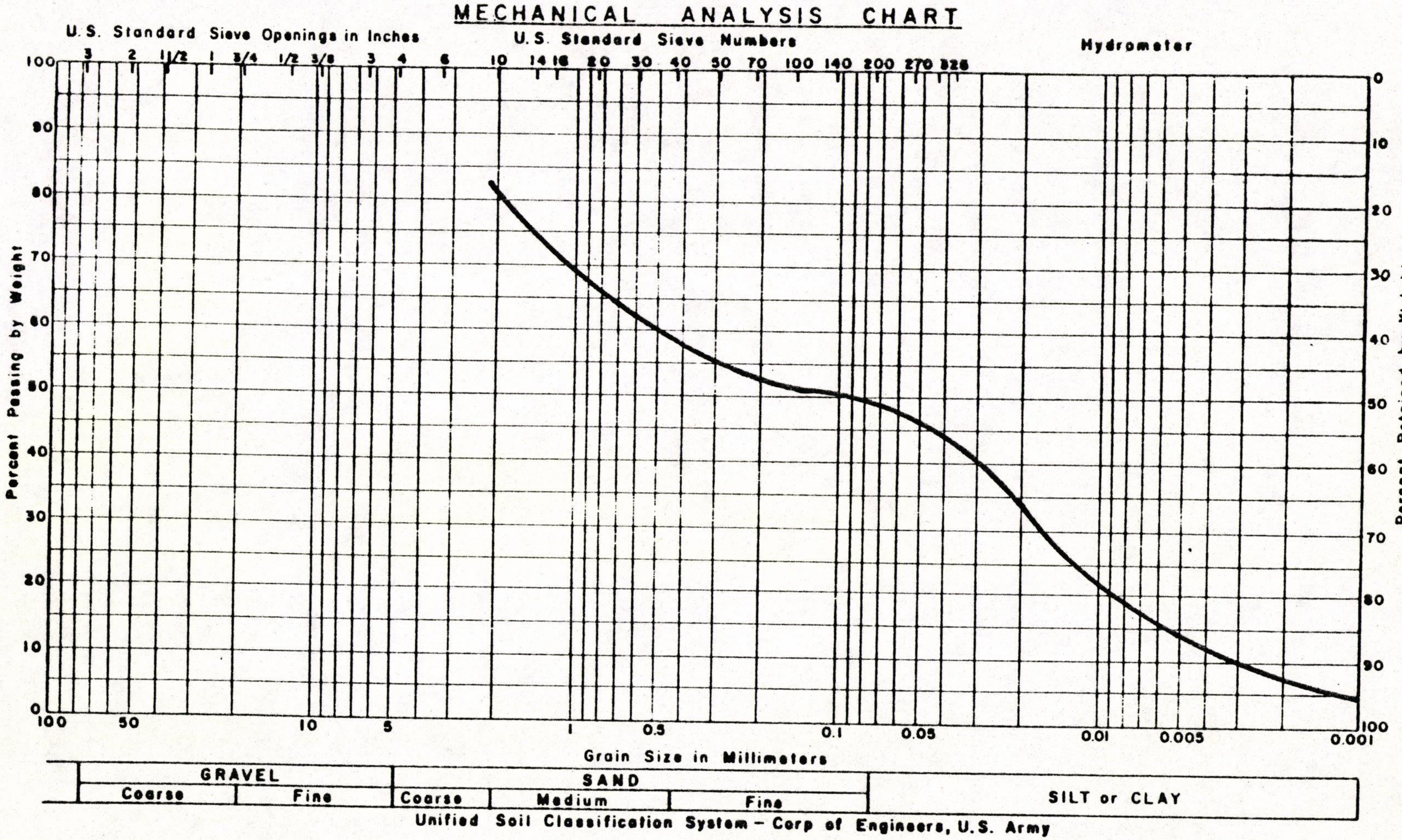

28 days, 10% Fly Ash
Section 2
ϕ = 12
Shear Strength (psi)
Confining Stress (psi)

Figure 46



Test Section = 2

70% Soil + 30% Fly Ash

Figure 47

CONCLUSIONS

1. Self hardening fly ash produced in Arkansas can stabilize road bases.
2. The strength of soil-fly ash mixtures may be reduced substantially by time delay between mixing and compaction.
3. Gypsum and some commerical cement retarders are effective in reducing the adverse effects of delayed compaction.
4. Fly ash stabilization works best in sands and clays because of better mechanical interlock with soil particles.
5. Fly ash characteristics vary widely. Quality control of ash used for stabilization is desirable.
6. Adequate mixing of soil and fly ash in the field is necessary.
7. Rapid compaction of soil and fly ash is necessary. Compaction should be completed within two hours after mixing.

REFERENCES

Abdun-Nur, E.A., 1961, "Fly Ash in Concrete: An Evaluation", Highway Research Board Bulletin 284, pp. 4-5

Allen, John J., David D. Currin, and D.H. Little, Jr., Jan 1977, "Mix Design, Durability and Strength Requirements for Lime Stabilized Layers in Airfield pavements", Transportation Research Board, 56th Annual Meeting.

ASTM, STP-377, 1964, "Compaction of Soils", pp. 80-101.

Cumberledge, G., Hoffman, G.L., and Bhajandas, A.C., 1976, "Curing and Tensile Strength Characteristics of Aggregate-Lime-Pozzolan", Transportation Research Record 560, pp. 21-28.

Dempsey, B.J. and Thompson, M.R., 1973, "Vacuum Saturation Method for Predicting Freeze-Thaw Durability of Stabilized Materials", Highway Research Record No. 442, pp. 44-55.

Dempsey, B.J. and Thompson, M.R., 1976, "Evaluation of Freeze-Thaw Durability of Stabilized Materials", Transportation Research Record 612, pp. 62-70.

DiGioia, A.M. and W.L. Nuzzo, June 1972, "Fly Ash as Structural Fill", Journal of the Power Division, ASCE, Vol 98, PO 1, pp. 77-92.

Faber, J.H. and DiGioia, Jr., A.M., 1976, "Use of Ash in Embankment Construction", Transportation Research Record 593, pp. 13-19.

Gray, D.H. and Y. Lin, April 1972, "Engineering Properties of Compacted Fly Ash", JSMFE, ASCE, Vol 98 SM4, pp. 361-379.

Johnson, A.W. and Sallberg, J.R., 1962, "Factors Influencing Compaction Test Results", Highway Research Board Bulletin 319.

Joshi, Ramesh C., Sept. 1978, "Structural Fills Using Fly Ash", Proceedings of the Ash Management Confrence at Texas A & M, College Station, Texas 77843.

Lambe, T.W., 1956, "Soil Testing for Engineers", pp. 43-48.

Lewis, T.S., 1976, "Construction of Fly Ash Roadway Embankment in Illinois", Transportation Research Record 593, pp. 20-23.

Mateos, M. and Davidson, D.T., 1963, "Compaction Characteristics of Soil-Lime-Fly Ash Mixtures:, Highway Research Record No. 29, pp. 27-40.

McDowel, C., 1959, "Stabilization of Soils with Lime, Lime-Fly Ash, and Other Lime Reactive Materials", Highway Research Board Bulletin 231, pp. 60-66.

Meyers, James F. et al., May 1976, "Fly Ash as a Construction Material for Highways", U.S. Dept. of Transportation, FHWA-IP-76-16.

Mitchell, J.K. and Hooper, D.R., 1961, "Influence of Time Between Mixing and Compaction of Properties of a Lime-Stabilized Expansive Clay", Highway Research Board No. 304, pp. 14-31.

National Cooperative Highway Research Program, 1976, "Lime-Fly Ash-Stabilized Bases and Subbases", Synthesis of Highway Practice 37, pp. 10-23.

Parker, D.G. and S.I. Thornton, 1977, "Permeability of Fly Ash and Fly Ash Stabilized Soils", National Technical Information Service, No. PB-265-229.

Seals, R.K., 1976, "Disposal Fills-Ash (Fly and Bottom)".

Smith, L.M. et al., December 1975, "Technology for Using Sulfate Waste in Highway Construction", Federal Highway Administrative Report H, FHWA-RO-76-31.

Sowers, G. B. and Sowers, G.F., 1970, "Introductory Soil Mechanics and Foundations", pp. 206-16.

Thornton, Sam I. and David G. Parker, 1975, "Fly Ash as Fill and Base Material in Arkansas Highways", National Technical Information Service, No. PB-250-480.

Thornton, S.I., D.G. Parker, and D.H. White, March 1976, "Soil Stabilization Using a Western Coal High Calcium Fly Ash", 4th International Ash Utilization Symposium, Energy Research and Development Administration MERC/SP-76/4.

Zube, Earnest, C.C. Gates, E.C. Shirley, and H.A. Munday, 1969, "Service Performance of Cement-Treated Bases as Used in Composite Pavements", Highway Research Record No. 291, pp. 57-69.