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EVALUATION AND FIELD VERIFICATION OF STRENGTH AND STRUCTURAL IMPROVEMENT OF CHEMICALLY STABILIZED SUBGRADE SOIL

Prepared by
Donald R. Snethen, Ph.D., P.E.
School of Civil and Environmental Engineering
Oklahoma State University

and

Gerald A. Miller, Ph.D., P.E., & Amy B. Cerato, Ph.D., P.E.
School of Civil Engineering and Environmental Science
University of Oklahoma

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16. Abstract

Often subgrade soils exhibit properties, particularly strength and/or volume change properties that limit their performance as a support element for pavements. Typical problems include shrink-swell, settlement, collapse, erosion or simply insufficient strength. A common approach to subgrade soil support or stability problems involves chemical modification or stabilization with additives such as lime (hydrated or quick), fly ash (Class C from lignite coal), cement kiln dust (CKD) or Portland cement. Other additives are available, but this group constitutes the major products or by-products used on roadway construction in Oklahoma.

The type and amount of chemical additive is dependent on the purpose or function of the treated material (i.e., improved physical properties or improved strength) and selection is based on accepted or standardized procedures. Questions then arise with regard to chemically treated subgrade soils about the rate of development and ultimate value of improvement. The purpose of this research is to develop relationships between rate of development and magnitude of strength (or physical property) improvement for chemically treated subgrade soils.

The research project involved laboratory and field studies of the influence of cementitious additives on the strength and structural improvement of stabilized subgrade soils. Laboratory tests for measuring strength and structural improvement (e.g. UCS and M_R) were conducted on field mixed treated soils and laboratory mixed treated and untreated soil samples. UCS and M_R tests were conducted on samples varying curing time (field and laboratory mixed) and percent additive used (laboratory mixed). A series of field tests (Nuclear w-γ, stiffness gauge, portable FWD, Dynamic Cone Pentrometer, and PANDA Pentrometer) were conducted at five field test sites on the untreated subgrade soils and on the treated subgrade soil with curing time as allowed by the construction schedule. The research project collected a large volume of both laboratory and field data which are summarized in the appendixes (5) to this report.

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Important conclusions concerning the verification of strength and structural improvement of stabilized subgrade soils include:

1. UCS and M_R values for field mixed samples are 50 to 90% of the laboratory mixed samples. Generally the higher the PI of the soils the greater the difference between field and laboratory conditions.
2. Measured UCS, M_R, and field parameters such as DCI and PTR indicate that typically 70% or more of the strength and structural improvement occurs in 7 days. The actual rate of improvement depends on such things as soil type, additive (type, amount, quality), construction procedure, and curing environment. Field measured parameters exhibited lower rates of improvement as compared to laboratory tests.
3. For additives, soils, and construction procedures used on the research project CKD yielded higher strengths more quickly than FA.
4. AASHTO-MEPDG Level 2 correlation equations significantly underestimate M_R and E values for the stabilized soils encountered in the research project.
5. The Dynamic Cone Pentrometer (expressed as DCI) and the PANDA Pentrometer (expressed as PTR) provide very good measures of long term performance of stabilized soils layers and show very good potential for use as quality control tools.

DISCLAIMER

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ODOT Division 7

Jeff Hiller, Construction Engineer

ODOT Anadarko Residency

Reese Knight, P.E., Resident Engineer

Johnny Walkup, Construction Project Manager

Leroy Smith, Construction Inspector

James Brit, Laboratory Manager

J & S Stabilization, Inc

ODOT Perry Residency

Ted Zachary, P.E., Resident Engineer

Tony Cross, Construction Inspector

Jay Gilbreath, Construction Inspector

Rick Schweer, Laboratory Manager

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City of Enid

Jason Brinley, P.E., Engineering Administration

Tom Cossin, Project Engineer

Abby Woods, CDBG Department Head

Cummins Construction (Mike Bier, Sam Eliman, Bob Pitman)

Morton Construction (Brandon Morton)

Payne County Road District 3

Jim Arthur, Commission, District 3

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E = Modulus of Elasticity, psi or ksi

M_R or M_r = Resilient Modulus, psi or ksi

UCS or q_u = Unconfined Compressive Strength, psi

MR = Modulus of Rupture

R = Resistance Value

CBR = California Bearing Ratio

P200 = Percent Passing U.S. No. 200 sieve

PI = Plasticity Index

DCP = Dynamic Cone Penetration

DCI = Dynamic Cone Index

μ = Poisson's Ratio

a_2, a_3 = Structural Coefficients

SN = Structural Number

K = Stiffness

γ = Density

w = Moisture Content

E_{vd} = Modulus from Portable FWD

PTR = PANDA Tip Resistance

SUMMARY

Often subgrade soils exhibit properties, particularly strength and/or volume change properties that limit their performance as a support element for pavements. Typical problems include shrink-swell, settlement, collapse, erosion or simply insufficient strength. A common approach to subgrade soil support or stability problems involves chemical modification or stabilization with additives such as lime (hydrated or quick), fly ash (Class C from lignite coal), cement kiln dust (CKD) or Portland cement. Other additives are available, but this group constitutes the major products or by-products used on roadway construction in Oklahoma.

The type and amount of chemical additive is dependent on the purpose or function of the treated material (i.e., improved physical properties or improved strength) and selection is based on accepted or standardized procedures. Questions then arise with regard to chemically treated subgrade soils about the rate of development and ultimate value of improvement. The purpose of this research is to develop relationships between rate of development and magnitude of strength (or physical property) improvement for chemically treated subgrade soils.

The research project involved laboratory and field studies of the influence of cementitious additives on the strength and structural improvement of stabilized subgrade soils. Laboratory tests for measuring strength and structural improvement (e.g. UCS and MR) were conducted on field mixed treated soils and laboratory mixed treated and untreated soil samples. UCS and MR tests were conducted on samples varying curing time (field and laboratory mixed) and percent additive used (laboratory mixed). A series of field tests (Nuclear w-γ, stiffness gauge, portable FWD, Dynamic Cone Pentrometer, and PANDA Pentrometer) were conducted at five field test sites on the untreated subgrade soils and on the treated subgrade soil with curing time as allowed by the construction schedule. The research project collected a large volume of both laboratory and field data which are summarized in the appendixes (5) to this report.

Important conclusions concerning the verification of strength and structural improvement of stabilized subgrade soils include:

1. UCS and MR values for field mixed samples are 50 to 90% of the laboratory mixed samples. Generally the higher the PI of the soils the greater the difference between field and laboratory conditions.
2. Measured UCS, MR, and field parameters such as DCI and PTR indicate that typically 70% or more of the strength and structural improvement occurs in 7 days. The actual rate of improvement depends on such things as soil type, additive (type, amount, quality), construction procedure, and curing environment. Field measured parameters exhibited lower rates of improvement as compared to laboratory tests.
3. For additives, soils, and construction procedures used on the research project CKD yielded higher strengths more quickly than FA.
4. AASHTO-MEPDG Level 2 correlation equations significantly underestimate MR and E values for the stabilized soils encountered in the research project.
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Chapter 1

INTRODUCTION

Background

Often subgrade soils exhibit properties, particularly strength and/or volume change properties that limit their performance as a support element for pavements. Typical problems include shrink-swell, settlement, collapse, erosion or simply insufficient strength. A common approach to subgrade soil support or stability problems involves chemical modification or stabilization (FHWA) with additives such as lime (hydrated or quick), fly ash (Class C from lignite coal), cement kiln dust or Portland cement. Other additives are available, but this group constitutes the major products or by-products used in roadway construction in Oklahoma.

The type and amount of chemical additive is typically selected using standardized procedures (ASTM, ODOT). In cases where the subgrade soil's strength is important in designing pavement thickness and predicting performance, ASTM D4609 test protocol is the best approach for selecting the type and defining the amount of soil additive.

Questions arise with regard to chemically treated subgrade soils about the rate of development and ultimate magnitude of improvement (strength increase or volume change stability) on construction projects. In other words, is the improvement response of field constructed soil layers the same as the laboratory mix design response? Potential differences between laboratory and field improvement responses may be the result of one or more of the following sources:

1. Normal variability of natural soils.
2. Variability (number and lateral extent) of soil types (i.e., assumption that one percentage of additive "fits" all the soils on the project).
3. Variability of field construction process (i.e., components, quality of workmanship).
4. Influence of climate

Typically, once the treated subgrade soil is compacted, the strength or volume change stability improvement is "assumed" to equal the laboratory mix design test results. The pavement is then designed using structural numbers based on historical, and sometimes, limited data reflecting the actual influence of the treated subgrade soil layer on the thickness and performance of the pavement. Often the strength improvement of the treated subgrade soil is simply ignored in the pavement design equation. Limited information is available on the rate of development and comparative magnitude of strength improvement of stabilized subgrade soils.

The "Guide for Mechanistic-Emperical Design of New and Rehabilitated Pavement Structures (MEPDG)" (AASHTO) uses an hierarchical (level) system for selecting or determining design inputs for pavement design. The system is based "on the philosophy that the level of engineering effort exerted in the pavement design process should be consistent with the relative importance, size, and cost of the design project". The three levels used in the MEPDG procedure are;

1. Level 1 is the most current implementable procedure available, normally involving comprehensive laboratory or field tests.
2. Level 2 requires that inputs are estimated through correlations with other material properties measured in the laboratory or field.
3. Level 3 requires an estimate of the most appropriate design input value of the material property based on experience with little or no testing.

This new or more organized approach to pavement design further highlights the need for a better understanding of the rate of development and comparative magnitude of strength improvement for stabilized subgrade soils, especially for Level 2 and 3 design inputs.

Objectives of Proposed Research

The purpose of the proposed research is to develop relationships between the rate of development and magnitude of strength improvement for chemically stabilized subgrade soils and pavement design input parameters. These relationships can be used to confirm and/or adjust pavement design input parameters currently recommended in the MEPDG to reflect Oklahoma soils, commonly used chemical additives, and pavement design experience.

The major objectives of the proposed research are:

1. Review existing correlations between chemically treated soils and AASHTO-MEPDG design input parameters.

2. Select roadway construction projects in grading and drainage stages of construction which represent different subgrade soil types and chemical additives used.
3. Collect representative soil samples from construction project locations for classification, quality control, and engineering property testing.
4. Collect representative chemically treated soil samples from construction project locations for engineering property testing.
5. Following compaction and acceptance of the chemically treated project locations conduct time sequenced field (tests) evaluation of strength and stiffness.
6. Using established time rate of development and maximum level of strength gain relationships, compare to previous/existing design input parameters correlations or experience-based lower limits and accept or adjust parameters accordingly.

The purpose of the Final Report is to present the results of the research project.

Chapter 2

REVIEW OF RELEVANT EXPERIENCES

Background

Chemically treated subgrade soils provide support to pavements and enhance the performance of the pavement system. Chemically treated soils influence performance by one or both of the following methods:

1. Improved physical properties such as reduced plasticity, reduced moisture-holding capacity, reduced shrink-swell response, and improved stability. This occurs at "lower" percentages of the chemical additive and is generally referred to as chemical modification of the soil. Basic chemical reactions between the additive and soil, include cation (typically calcium or magnesium) exchange and agglomeration/flocculation.
2. Improved strength of the treated soil, which obviously increases the common strength characterization parameters, i.e., unconfined compressive strength, resilient modulus, and stiffness. This occurs at "higher" percentages of the chemical additive and is generally referred to as chemical stabilization of the soil. Basic chemical reactions between the additive and soil include the same cation exchange and agglomeration/flocculation that occurs in soil modification plus the development of pozzolanic reaction products that "stick" the soil particles together. The level of development of pozzolanic reaction products is dependent on the amount of chemical additive, time, pH, and temperature. The pozzolanic reaction products are strong, durable, and provide long-termed performance when properly selected and constructed.

Alternatively, chemical additives and the influence they have on subgrade soils may be characterized as non-cementitious or cementitious, which is similar in context to the modification versus stabilization categorization. Non-cementitious chemical additives provide a source of cations which interact with the soil minerals in the form of cation exchange and agglomeration/flocculation and any pozzolanic reaction products are limited because the necessary chemicals to form the reaction products must be "provided" by the soil mineral. Lime is considered a non-cementitious chemical. Cementitious chemical additives provide both a source of cations for modification reactions and a source of the "building blocks" for pozzalonic reaction products, specifically silica and alumina. In other words, at appropriate percentages of cementitious chemical additives, sufficient cations, silica, and alumina are available to modify the soils physico-chemical properties as well as stabilize the soils with pozzolanic reaction products. Flyash (class C), cement kiln dust (CKD), and Portland cement are cementitious chemicals.

Mechanical-Empirical Pavement Design Guide

In the Mechanical Empirical Pavement Design Guide (MEPDG), "the chemically stabilized materials group consists of lean concrete, cement stabilized, open grade cement stabilized, soil cement, lime-cement-flyash, and lime treated materials". Lean concrete, cement stabilized, open graded cement stabilized, and soil cement are high quality (i.e., high strength) materials consisting of mixtures of natural granular or graded coarse and/or fine aggregates and cement. Mix design procedures can confidently define the amount of strength improvement. Lime, cement (more often CKD) and flyash or combinations of additives are more commonly used in fine-grained soils, so whether strength improvement occurs or how much occurs is more difficult to determine. In the MEPDG, fine-grained soils treated with cementitious chemical additives would be considered in the "chemically stabilized materials group", while fine-grained soils treated with non-cementitious chemical additives would be considered in the "unbound granular and subgrade materials group".

According to the MEPDG, input parameters for design for chemically stabilized materials group are:

- Elastic Modulus
- Resilient Modulus
- Modulus of Rupture
- Poisson's Ratio
- Thermal Conductivity
- Heat Capacity

For unbound granular and subgrade materials input parameters to design include:

- Resilient Modulus
- Poisson's Ratio
- Classification and other properties (for Climate Model)

The MEPDG uses more sophisticated models for analyzing the performance of chemically stabilized materials than for unbound granular and subgrade materials. A more detailed explanation of the different models appears in the MEPDG.

Since the purpose of the review of relevant experiences is to summarize laboratory and field research experiences of DOT's with regard to performance of chemical additives for modification/stabilization of subgrade soils, it's helpful to understand how the various measured laboratory and field properties relate to the required input parameters for the MEPDG. The input parameters discussed in subsequent paragraphs will emphasize Level 2 and 3 inputs since confirmation of these parameters for typical Oklahoma soils is a part of the purpose of this research project.

Level 2 correlations with other material properties or modulus values for the chemically stabilized material group are shown in Table 2.1 (MEPDG Table 2.2.42)

Table 2.1. Models/Relationships used for determining Level 2 E or M_r (from MEPDG)

Chemically Stabilized Material	Recommended Relationships*
Lean concrete[1] Cement treated aggregate[1]	$E=57000\sqrt{f_c^1}$ (*18*) where, E is the modulus of elasticity, psi; f^1_c=compressive strength, psi, tested in accordance with AASHTO T22
Open graded cement stabilized	No correlation are available
Soil cement[2]	$M_r=1200*q_u$(*18*) where, E is the modulus of elasticity, psi; q_u=unconfined compressive strength, psi, tested in accordance with ASTM D 1633, "Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders"
Lime-cement-flyash[2]	$E=500+q_u$(*19*) where, E is the modulus of elasticity, psi; q_u=unconfined compressive strength, psi tested in accordance with ASTM C 593, "Standard Specifications for Fly Ash and Other Pozzolans for use with Lime"
Lime stabilized soils[2]	$M_r=0.124q_u+9.98$(*17*) where, M_r=resilient modulus, ksi q_u=unconfined compressive strength, psi, tested in accordance with ASTM D 5102, "Standard Test Method for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures"

[1]Compressive strength f_c can be determined using AASHTO T22.
[2]Unconfined compressive strength q_u can be determined using the MDTP.

Level 3 typical modulus values for the chemically stabilized material group, are shown in Table 2.2, (MEPDG Table 2.2.43) and 2.3 (MEPDG Table 2.2.44)

Table 2.2. Summary of typical modulus values for chemically stabilized materials. (from MEPDG)

Chemically Stabilized Material	E or M_r Range, psi	E or M_r Typical, psi
Lean concrete	1,500,000 to 2,500,000	2,000,000
Cement stabilized aggregate	700000, to 1,500,000	1,000,000
Open graded cement stabilized aggregate	--	750,000
Soil cement	50,000 to 1,000,000	500,000
Lime-cement-flyash	500,000 to 2,000,000	1,500,000
Lime stabilized soils*	30,000 to 60,000	45,000

*For reactive soils with 25 percent passing No. 200 sieve and PI of at least 10.

Table 2.3. Summary of typical modulus values for deteriorated chemically stabilized materials. (from MEPDG)

Chemically Stabilized Material	Deteriorated M_r Typical, psi
Lean concrete	300,000
Cement stabilized aggregate	100,000
Open graded cement stabilized	50,000
Soil cement	25,000
Lime-cement-flyash	40,000
Lime stabilized soils	15,000

Level 2 correlations with other material properties for modulus of rupture (flexural strength) for the chemically stabilized material group are shown in Table 2.4 (MEPDG Table 2.2.46)

Table 2.4. Relationship between unconfined compressive strength and flexural strength for chemically stabilized materials. (from MEPDG)

Chemically Stabilized Material	Test Protocol	Typical MR, psi
Lean concrete	AASHTO T 22	MR can be conservatively estimated as being 20 percent of the q_u (*15*)
Cement treated aggregate		
Open graded cement stabilized aggregate	Not available	--
Soil cement	ASTM D 1633	MR can be conservatively estimated as being 20 percent of the q_u (*15*)
Lime-cement-flyash	ASTM C 593	
Lime stabilized soils	ASTM D 5102	

Level 3 typical modulus of rupture values for the chemically stabilized material group are shown in Table 2.5 (MEPDG Table 2.2.47)

Table 2.5. Typical flexural strength (MR) values for chemically stabilized materials. (from MEPDG)

Chemically Stabilized Material	Typical MR, psi
Lean concrete	450
Cement stabilized aggregate	200
Open graded cement stabilized	200
Soil cement	100
Lime-cement-flyash	150
Lime stabilized soils	25

Recommended ranges of Poisson's ratio for the chemically stabilized material group are shown in Table 2.6 (MEPDG Table 2.2.48)

Table 2.6. Recommended ranges of Poisson's ratio for chemically stabilized materials. (from MEPDG)

Material	Poisson's Ratio
Cement Stabilized Aggregate (including Lean Cement)	0.1 to 0.2
Soil cement	0.15 to 0.35
Lime-Fly Ash Materials	0.1 to 0.15
Lime stabilized soils	0.15 to 0.2

Thermal conductivity and heat capacity are inputs to the climate model used to estimate temperature and moisture profiles in the pavement structure and subgrade. More details on estimating thermal properties are available in the MEPDG.

Level 2 correlations with other material properties for resilient modulus for the unbound granular and subgrade materials group are shown in Table 2.7 (MEPDG Table 2.2.50)

Table 2.7. Models relating material index and strength properties to M_r. (from MEPDG)

Strength/Index Property	Model	Comments	Test Standard
CBR	$M_r=2555(CBR)^{0.64}(TRL)$ M_r, psi	CBR –California Bearing Ratio, percent	AASHTO T 193, "The California Bearing Ratio"
R-value	$M_r=1155+555R$(*20*) Mr, psi	R=R-value	AASHTO T 190, "Resistance R-Value and Expansion Pressure of Compacted Soils"
AASHTO layer coefficient	$M_r=30000\left(\frac{a_i}{0.14}\right)$(*20*) M_r, psi	a_i=AASHTO layer coefficient	AASHTO Guide for the Design of Pavement Structures
PI and gradation*	$CBR=\frac{75}{1+0.728(wPI)}$ (see Appendix CC)	wPI=P200*PI P200-percent passing No. 200 sieve size PI=plasticity index, percent	AASHTO T 27. "Sieve Analysis of Coarse and Fine Aggregates" AASHTO T 90. "Determining the Plastic Limit and Plasticity Index of Soils"
DCP*	$CBR=\frac{292}{DCP^{1.12}}$	CBR=California Bearing Ratio, percent DCP=DCP index, mm/blow	ASTM D 6951, "Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Application"

*Estimates of CBR are used to estimate M_r

Level 3 typical resilient modulus values for the unbound granular and subgrade material group are shown in Table 2.8 (MEPDG Table 2.2.51)

Table 2.8. Typical resilient modulus values for unbound granular and subgrade materials (modulus at optimum moisture content) (Appendix CC). (from MEPDG)

Material Classification	M_r Range	Typical M_r
A-1-a	38,500-42,000	40,000
A-1-b	35,500-40,000	38,000
A-2-4	28,000-37,500	32,000
A-2-5	24,000-33,000	28,000
A-2-6	21,500-31,000	26,000
A-2-7	21,500-28,000	24,000
A-3	24,500-35,500	29,000
A-4	21,500-29,000	24,000
A-5	17,000-25,500	20,000
A-6	13,500-24,000	17,000
A-7-5	8,000-17,500	12,000
A-7-6	5,000-13,500	8,000
CH	5,000-13,500	8,000
MH	8,000-17,500	11,500
CL	13,500-24,000	17,000
ML	17,000-25,500	20,000
SW	28,000-37,500	32,000
SP	24,000-33,000	28,000
SW-SC	21,500-31,000	25,500
SW-SM	24,000-33,000	28,000
SP-SC	21,500-31,000	25,500
SP-SM	24,000-33,000	28,000
SC	21,500-28,000	24,000
SM	28,000-37,500	32,000
GW	39,500-42,000	41,000
GP	28,000-40,000	34,500
GW-GC	28,000-40,000	34,500
GW-GM	35,500-40,500	38,500
GP-GC	28,000-39,000	34,000
GP-GM	31,000-40,000	36,000
GC	24,000-37,500	31,000
GM	33,000-42,000	38,500

Significant caution is advised when selecting resilient modulus values from Table 2.8 because the values are “very approximate”. Levels 1 or 2 are strongly preferred.

The MEPDG does not provide correlations with other material properties for Poisson’s ratio (i.e. Level 2) for unbound granular and subgrade material group. It recommends using “local knowledge and experience.” Level 3 typical Poisson’s ratio values for unbound granular and subgrade materials group are shown in Table 2.9 (MEPDG Table 2.2.52).

Table 2.9. Typical Poisson's ratio values for unbound granular and subgrade materials. (From MEPDG)

Materials Description	μ Range	μ Typical
Clay (saturated)	0.4—0.5	0.45
Clay (unsaturated)	0.1—0.3	0.2
Sandy clay	0.2—0.3	0.25
Silt	0.3—0.35	0.325
Dense sand	0.2—0.4	0.3
Coarse-grained sand	0.15	0.15
Fine-grained sand	0.25	0.25
Bedrock	0.1—0.4	0.25

Classification and other properties are used in the climate model to estimate temperature and moisture profiles in the pavement structure and subgrade. More details on measuring or estimating the required input parameters are available in the MEPDG.

The correlations with other material properties and typical values presented in the MEPDG are referred to a number of sources and appear to be compilations and summaries of relationships and limiting values presented in or interpreted from the various sources. In other words, the information in the tables does not appear, in the form presented, in any of the reference sources. As far as research into calibrating or characterizing input parameter for stabilized materials or unbound subgrade soils is concerned, members of the MEPDG Implementation Group (contacted and replied by email) were not aware of any research directed at the input parameters. Several research projects involving laboratory and field performance of chemical additives along with some comparative evaluations of mechanistic empirical pavement designs including (or omitting) MEPDG design input were obtained using various information search websites as well as federal and state DOT websites. The remainder of this chapter summarizes several of those documents.

Contribution of Treated Soil Layers in Pavement

Qubain, Seksisnky, and Li evaluated the influence of a lime-stabilized subgrade soil layer had on the resultant pavement thickness for a project involving widening and reconstruction of a section of the Pennsylvania Turnpike. The subgrade soils were fairly uniform medium to stiff clays. The effects of lime stabilized layers were incorporated in the pavement design (AASHTOWare DARWin 3.01 computer program) using three options:

1. Using an appropriate resilient modulus for the lime stabilized layer
2. Using a CBR of 15 for the treated layer
3. Considered lime treated layer as subbase and assigned it a structural number.

Laboratory test result on the subgrade soil are presented in Table 2.10 (Qubain, et al)

Table 2.10. Laboratory Testing Results (from Qubain, et al).

Sample	USCS	Water Content (%)	Liquid Limit (%)	Plasticity Index (%)	Dry Density (g/cm^3)	Optimum Water (%)	Swell (%)	CBR (%)	M_R (kPa)
Natural	CL	16.9	37	13	1.73	17.7	1.4	8	64,000
Lime-treated	--	16.4	34	10	1.73	15.1	1	37	250,000

Using consistent pavement design input parameters for each of the three cases, the resulting pavement thicknesses are summarized in Table 2.11 (Qubain, et al).

Table 2.11. Pavement Comparisons for Different Design Approaches

Pavement Layers	Layer Thickness (mm) Lime-Stabilized Subgrade			Layer Thickness (mm) Non-Stabilized Subgrade		
	M_R= 165000kPa	CBR = 15	Structural Coefficient = 0.11	Preliminary CBR = 5	M_R = 60000 kPa	CBR = 8
AC	130	130	130	130	130	130
BCBC	130	130	170	330	300	250
ATPBC	100	100	100	100	100	100
PennDOT 2A	130	150	150	200	200	200
Total Thickness	490	510	550	760	730	680

The lime stabilized layer CBR of 15 should be compared to the untreated subgrade CBR of 8 (Column 2 vs. Column 6) for a reduction in thickness of 170 mm. A more dramatic difference occurs between resilient modulus inputs (Column 1 vs. Column 5) or 220 mm. Over the length of the project the authors estimated a 20% saving in cost or about $4.5

million by using lime and incorporating the change in the subgrade properties in the design of the pavement.

Shafee Yusut, Little, Sarkor completed a research project for the Mississippi DOT to assess material properties and performance of lime-treated subgrades. Soil samples were collected from four project locations and field tests were conducted on the pavements, each of which had a lime-treated subgrade layer. Laboratory tests (Unconfined Compression and Resilient Modulus Tests) were conducted on stabilized and unstabilized soil specimens. Field tests (Falling Weight Deflectometer and Dynamic Cone Penetrometer) were conducted on the lime-treated layers and the untreated subgrade soil beneath the lime-treated layer. Comparisons between stabilized and unstabilized soils were made for both laboratory and field tests. Table 2.12 summarizes the laboratory test results and Table 2.13 summarizes the field test results.

Table 2.12. Unconfined Compressive Strength and Resilient Moduli of Mississippi Soils (from Yusut, et al)

Soil I.D.	Curing Condition	Unstabilized Soil		Stabilized Soil		Ratio (Stabilized /Unstabilized)
		Individual	Average	Individual	Average	
Unconfined Compressive Strength (kPa) of Dry Specimens						
US 61 N Washington Co.	7-days @ 40˚C	2342	2175	3056	3308	1.52
		2008		3559		
US 82 E Washington Co.	7-days @ 40˚C	1912	1993	3661	3473	1.74
		2074		3284		
US 82 W Lowndes Co.	7-days @ 40˚C	2604	2620	2349	2134	0.81
		2636		1919		
US 45 N Kemper Co.	7- days @ 40˚C	1740	1700	3008	2734	1.61
		1660		2460		
Unconfined Compressive Strength (kPa) of Soaked Specimens						
US 61 N Washington Co.	30-days @ 25˚C	2	14	1585	1704	125
		10		1461		
		29		2067		
	7-days @ 40˚C	25	31	1827	1987	63
		32		2030		
		37		2104		
US 82 E Washington Co.	30-days @ 25˚C	20	8	1249	1506	188
		2		1650		
		2		1620		
	7-days @ 40˚C	41	42	2080	1885	45
		58		1803		
		26		1773		
US 82 W Lowndes Co.	30-days @ 25˚C	1	1	1198	1356	1017
		1		1298		
		2		1573		
	7-days @ 40˚C	1	1	1729	1678	1678
		1		1650		
		1		1654		
US 45 N Kemper Co.	30-days @ 25˚C	4	8	1158	1445	188
		6		1486		
		13		1690		
	7-days @ 40˚C	15	16	1788	1930	118
		26		2072		
		8		1931		
Resilient Modulus (MPa) of Dry and Soaked Specimens						
US 61 N Washington Co.	Dry	288	294	530	516	1.76
		300		502		
	Wet	NT		415	415	
US 82 E Washington Co.	Dry	217	257	377	353	1.37
		297		329		
	Wet	NT		201	201	
US 82 W Lowndes Co.	Dry	252	234	404	399	1.70
		216		393		
	Wet	NT		260	260	
US 45 N Kemper Co.	Dry	340	373	520	517	1.39
		405		514		
	Wet	55	55	367	367	6.67

Note: NT = Not Tested

Table 2.13. Results for LTS and Unstabilized Subgrade for Mississippi Pavements. (From Yusut, et al)

Pavements	GPT Results		FWD Results			DCP Results			
	Layer Thickness (mm)	Dielectric Constant	Subgrade Moduli (MPa)	LTS Moduli (MPa)	Ratio (LTS/ Subgrade)	Layer Thickness (mm)	Subgrade CBR	LTS CBR	Ratio (LTS/ Subgrade)
US 61 N Washington County	HMA: 250 LTS: 150	9 – 13	79	425	4.38	LTS: 125	15	500	33.33
US 82 E Washington County	HMA: 325 LTS: 150	6 – 8	119	2466	20.72	LTS: 125	12	150	12.50
US 82 W Lowndes County	HMA: 363 LTS: 150	7 – 10	123	1350	10.98	LTS: 150	4	47	11.75
US 45 N Kemper County	HMA: 250 LTS: 250	No Data	125	1482	11.86	LTS: 275	10	133	13.30

The ratios of stabilized to unstabilized properties, with one exception for laboratory testing, all show moderate to significant improvements in measured properties when lime was used.

A subsequent paper by Mallela, Quontas, and Smith accumulates experience on the use of lime to treat highway subgrades and correlates the information with the MEPDG. This is a good reference which expands some of the topics included in the MEPDG relating to treatment of subgrade soils with lime.

Performance of Chemically Treated Subgrade Soils

Over the past seven years, a number of laboratory and field research studies have evaluated short- and long-term performance of chemical additives for modifying and stabilizing subgrade soils. The following paragraphs describe the reported results of these studies.

Kentucky Experiences

The Kentucky Transportation Cabinet (KYTC) and the University of Kentucky Transportation Center (UKTC) (Hopkins, et al) undertook a research study of 20 selected roadway sections on 14 roadway projects that had been stabilized with lime or cement to improve the subgrade soils' properties and pavement performance. The research involved a forensic evaluation of the stabilized subgrade soils in which borings through the pavement and subgrade were conducted to obtain soil samples and run in situ CBR tests. Falling Weight Deflector (FWD) tests were run on the pavements prior to the borings. Some of the "significant findings and recommendations" are summarized as follows:

1. Measured in situ CBR values at the 85th percentile value for various soil additives were:

Lime Kiln Dust (LKD)	24
Hydrated Lime	27
Hydrated Lime/Portland Cement	32
Portland Cement	59
Atmospheric Fluidized Bed Composition (AFBC) Ash	9
Untreated	2

   Age of pavement test sections varied between 8 and 15 years. The study concluded "that chemically treated subgrades are very durable and long lasting".

2. Structural credit of chemically stabilized soil subgrades in the design of pavements was established based on a relationship published by AASHTO relating CBR and structural layer coefficient, a_3. Using the 85th percentile CBR values from above, the structural coefficient, a_3, of subgrades mixed with LKD, hydrated lime, hydrated lime/Portland cement, Portland cement, and AFBC ash were 0.1, 0.106, 0.11, 0.13 and 0.08, respectively. For pavement test sections , "backcalculated" or "in service" structural coefficients were:

Soil – hydrated lime subgrades (4)	0.05, 0.09, 0.10 and 0.19
Soil – Portland cement subgrades (3)	0.10, 0.16 and 0.18
Soil – LKD subgrades (1)	0.10
Soil – AFBC subgrades (2)	0.09 and 0.15

   Age of pavement test sections varied between 12 to 15 years. Positive structural layer coefficients indicate that thinner pavement sections could be (and were) used for the pavement design. The remaining pavement test sections in the study had back calculated structural coefficients, a_3, of 0 to 0.03. No structural credit would have been given for these stabilized subgrades in the pavement design.

3. "Chemical stabilization substantially increased the elastic modulus of untreated soils at all sites. Back-calculated values of modulus obtained from FWD tests of subgrades mixed with chemical admixture are about two times greater than back-calculated values of modulus of untreated soils."
4. Chemical stabilization represents a very economical means of improving the poor engineering strengths of Kentucky soils. Based on structural number, SN, required by the 1981 Kentucky flexible pavement design curves, the cost of pavement sections constructed on stabilized soil subgrades are less than equivalent pavement sections constructed on non-stabilized soil subgrades. Moreover, the thickness of a pavement resting on a treated subgrade can be thinner than the thickness if a pavement resting on an untreated subgrade. For a flexible pavement measuring 36 feet in width, the average cost savings for soil-hydrated lime and soil-cement subgrade stabilization was 19,100 dollars per mile.

<u>OU/ODOT Research</u>

The OU School of Civil Engineering conducted a study (Miller, et al) to evaluate cement kiln dust (CKD) as a soil stabilizer, which compared the laboratory and field behavior of CKD from three sources in Oklahoma and calcium oxide (quick lime). The field study involved construction of four test sections along a rural highway in Oklahoma. Soil samples were collected before, during field mixing, and following compaction for laboratory testing. Field testing included Dynamic Cone Penetration (DCP) of the treated subgrade and FWD testing after the pavement construction. In addition, an in-depth laboratory study was conducted on a clay and sand soil taken adjacent to the field test section. The laboratory study included plasticity, unconfined compressure strength, durability (freeze-thaw, wet-dry), swell and CBR. Results of the field study showed that the performance of CKD varied with the source (i.e., characteristics) of the CKD. The laboratory study showed that overall, CKD was at least as effective if not more effective than quick lime for the clay soil. For sand, CKD (a cementitious material) was clearly a more effective stabilizer than quick lime. CKD performed similarly to quick lime for reducing plasticity. CKD treated soils were more durable than quick lime treated soils. The study recommended that because of the variability of CKD, its use as a chemical additive should be evaluated on a case-by-case basis.

Kansas Experience

In a laboratory study conducted at Kansas University, (Milburn and Parsons) evaluated the performance of eight soils with lime (hydrated), cement, fly ash (Class C) and a proprietary liquid chemical (PermaZyme 11-X). The study evaluated the influence of the chemicals on the plasticity, strength, durability (freeze-thaw, wet-dry), leaching, and stiffness properties of the soils tested. Some of the general conclusions reached during the study are summarized in the following:

1. Lime, fly ash, and cement were effective in improving the plasticity characteristics of the soils tested, with lime showing the most influence on PI.
2. Lime, fly ash, and cement dramatically lowered the swell of CL soils. Most of the CH soils, with sulfates, swelled the same or more than the untreated soils.
3. Lime, fly ash, and cement treated soils exhibited significant strength improvements while the enzyme-treated soils showed modest strength gains. Most strength gains were retained after durability and leaching testing. Lime and cement treated soils performed best after durability testing.
4. Lime and cement treated soils exhibited higher stiffness than fly ash treated soils.
5. The liquid enzyme stabilizer did not substantially improve soil performance.

The study recommended that the function of the chemical additive (reduced plasticity, reduced swell, increased strength) should be considered in selecting the type of additive. Selection of the amount of chemical additive should be based on various guidelines for each of the various chemicals (i.e. ASTMD6276 for lime). Caution should be taken for treatment of sulfate rich soils with calcium based chemicals.

A research study at Kansas State University (Romanoschi, et al) conducted at the Civil Infrastructure Systems Laboratory (CISL) using accelerated pavement testing (APT) methods evaluated the performance of Portland cement, fly ash, lime and a commercial product (EMC^2) as a soil additive to one soil in an accelerated traffic loading environment. Four flexible pavement test sections were constructed and tested under full scale traffic loading conditions. A companion laboratory study was conducted to characterize the influence of each of the chemical additives on the test soil. Some of the major findings of the research are summarized in the following:

1. Under traffic loading conditions lime was the most effective stabilizer for the soil used in the research. Cement was next most effective followed by fly ash and the commercial product. The evaluation was based on "vertical compressive stresses at the top of the unbound clayey subgrade" which were measured during testing.
2. From the laboratory testing programs lime, Portland cement, and fly ash reduced swell and increased the unconfined compressive strength of the soil. The highest unconfined compressive strength was exhibited by cement, followed by lime and fly ash.

The study recommended the use of lime as the chemical stabilizer for clayey non-sulfate soil, with properties similar to that used in the traffic test. "Stabilization with lime leads to better pavement performance than stabilization with cement, even though soil-cement has higher compressive strength than that of lime stabilized soil."

Mississippi Experience

The Mississippi Department of Transportation (MDOT) conducted a study (Bartes and Bartes and Metcalf) of the long term performance of lime-fly ash (LFA) stabilized soil as a base course material. The field portion of the study included performing FWD tests on newer and older pavements and coring the pavements at each FWD location to observe layer conditions, pavement thicknesses and obtain cores for laboratory unconfined compressive strength (UCS) testing. The measured parameters were used to calculate layer (LFA layer) structural layer coefficients. The field and laboratory testing programs were conducted at nine sites using similar soils for the LFA treated base courses (mostly A-2-4). Table 2.14 from Bartes and Metcalf shows the calculated structural layer coefficient for the LFA stabilized layers.

Table 2.14. Summary of Structural Layer Coefficients (from Bartes and Metcalf)

Route	Number of Tested Locations	Normalized LFA a_2 Average	Normalized LFA a_2 Coef. of Var.	HMA a_1 Average
Newer Projects				
Bolivar	16	0.216	25.4	0.465
US-61				
US-45	16	0.273	18.9	0.462
Hwy. 35	15	0.214	22.7	0.423
US-72	8	0.177	30.7	0.44
Wilkinson US-61	8	0.259	50.3	0.448
Summary	63	0.232	32	0.451
Route	Number of Tested Locations	LFA a_2 Based on Equation 3 Average	LFA a_2 Based on Equation 3 Coef. of Var.	Revised HMA a_1 Calculated from Revised SN_{eff}
Older Projects				
Forrest US-98	16	0.18	22.3	0.38
George US-98	8	0.186	25.1	0.312
US-84	16	0.155	13.7	0.434
Hwy. 7	16	0.152	36.6	0.434
Summary	56	0.165	23.3	0.401

Typically MDOT design uses a structural layer coefficient of 0.2 for a LFA mix design based on a UCS of 500 psi. All but one of the newer projects met or exceeded the typical value while all of the older projects were less than the typical value. This leads to the following conclusions drawn by the authors from the results of the study.

1. LFA base courses, used on over 600 projects, are a "variable product in terms of structural value and thickness". Changes in construction practice were recommended to ensure more uniform placement.
2. Placement conditions were increased to 100% Standard Proctor density and in situ UCS of 400 psi.
3. The typical LFA stabilized base course layer was increased from 6 to 8 inches and a 6-inch chemically stabilized subgrade layer was required for additional support. The LFA layer structural coefficient was maintained at 0.2.

Nebraska Experience

The Nebraska Department of Roads (NDOR) in conjunction with the University of Nebraska is currently investigating the performance of lime, CKD, and fly ash for use as stabilizing agents with a variety of Nebraska soils. The research study has as its objective to develop guidance for use and a draft set of specifications for incorporating these chemicals into local soils to improve stability, increase soil strength, and reduce swell characteristics of subgrade.

Chapter 3

LABORATORY AND FIELD TESTING PROGRAMS

In order to achieve the objectives of the proposed research, an extensive laboratory and field testing program was undertaken. Five sampling/monitoring sites were selected, representative soil samples of the local soils were collected for classification testing and soil-additive mix design procedures. During construction of the stabilized subgrades, field mixed samples were collected for strength development with time testing. Following construction of the stabilized subgrades, a series of field tests were conducted with time to measure strength development for the treated soil layer. Results of all the laboratory and field tests were used to evaluate and verify the strength and structural improvement of the treated subgrade soils

Field Test Site Selection Criteria

To facilitate location and selection of the field test sites, some general requirements were defined:

1. New construction or reconstruction where subgrade soils would be chemically stabilized.
2. Prefer fine-grained soils (A-4, A-5, A-6) but would consider A-2 soil groups.
3. Chemical additive type – open to what's specified by roadway design or selected by contractor (fly ash, cement kiln dust, cement, line). Amount of additive should be at stabilization level.
4. Field sites within about 120 miles of Stillwater.
5. Prefer field sites where grading/drainage would be completed during winter 2006-07 and scheduled for chemical treatment during Spring or Summer 2007.
6. Prefer field sites where chemically treated subgrade would be available for field testing (e.g. before paving) for 7 to 14 days or more.
7. No preferences on pavement surface type or highway section type.

ODOT Bid Tabs were used to select potential sites, then contacts were made with Division and/or Resident personnel. After careful evaluation, five field test sites were selected which represented city, county, and state (e.g. ODOT) projects. The five field test sites are described in the following paragraphs.

Oakdale Drive – North, Enid

This project is located in Enid, OK on Oakdale Drive, at the north end of a street replacement project approximately one-half mile long. The existing asphalt pavement was milled to top of subgrade between existing concrete curbs. The subgrade is a low to moderate plasticity sandy clay (A-6(1), SC) with a natural water content of 13.8% and dry density of 130.7 pcf. The City of Enid Engineering office selected cement kiln dust (CKD) as the treatment additive at a rate of 14% for a 6-8 inch layer. Soil samples were collected the day after completion of the pavement milling and field testing was started after construction of the treated subgrade.

Oakdale Drive – South, Enid

This project is located in Enid, OK on Oakdale Drive at the south end of a street replacement project approximately one-half mile long. The existing asphalt pavement was milled to the top of subgrade between existing concrete curbs. The subgrade is a non-plastic silty sand (A-2-4, SM) with a natural water content of 8.5% and dry density of 126.2 pcf. The City of Enid Engineering office selected cement kiln dust (CKD) as the treatment additive at a rate of 14% for a 6-8 inch layer. Soil samples were collected the day after completion of pavement milling and field testing was started after construction of the treated subgrade.

US62, Anadarko

This project is located on US62 east of Anadarko along a section where two additional lanes were added to an existing two-lane road. Grading and draining were completed and the subgrade soils were treated with 12% class C fly ash for a 6 inch layer. The subgrade is a non-plastic sandy silt (A-4, ML) with a natural water content of 7.0% and dry density of 117.1 pcf.

15th Street, Perry

This ODOT project involved replacement of 15th Street on the west edge of Perry, OK. The existing asphalt pavement was milled to the top of subgrade. The subgrade is a moderate plasticity silty clay (A-6 (16), CL) with a natural water content of 22.0% and dry density of 103.7 pcf. The subgrade was treated with 12% class C fly ash to a depth of 6(+) inches.

Country Club Road, Payne County

The Payne County, District 3 project involved paving of a gravel road for improvement to local county standards. The subgrade soil is a low plasticity sandy clay (A-4(2), CL) with a natural water content of 13.9% and dry density of 111.8 pcf. A county crew treated the subgrade with approximately 30% class C fly ash to a depth of about 3-4 inches. Construction involves motor graders and rolling windrows to mix the soil and additive.

Laboratory Testing Programs

The laboratory testing programs were conducted on untreated and treated soil samples from each of the five field test sites. Representative soil samples of the untreated subgrade were collected from each site prior to the stabilization of the subgrade soils. Approximately 500 lbs of soil was obtained from three locations over a length of approximately 100 ft of the subgrade. The soil samples were temporarily stored on double plastic bags, transported to the laboratory, then dried and processed for the various testing programs. The untreated soil samples were used for classification tests and a laboratory mix design for the additives used at each field test site.

During construction in the area sampled, representative samples of dry-mixed soil and additive were collected from three locations over the same 100 ft section of the treated subgrade. The dry field-mixed samples were temporarily stored in double plastic bags, transported to the laboratory, then molded into test specimens for unconfined compression tests (UCT) and resilient modulus (M_R) tests.

Untreated Soil Samples

Representative test specimens were prepared from the untreated soil samples and the following tests were conducted:

1. Percent minus US No. 200
2. Atterberg Limits (Liquid Limit, Plastic Limit, Plasticity Index)

3. Bar Linear Shrinkage
4. Standard Proctor Compaction (with Harvard Miniature Compaction Correlation for UCT Specimens)
5. Unconfined Compression Test (UCT)
6. Resilient Modulus Test (M_R)

These tests established basic physical properties, soil classification categories, and base line strength and modulus values for the untreated soils at each field test site.

Field-Mixed Soil Samples

Representative test specimens were prepared from the dry field-mixed soil samples and the following tests were conducted:

1. Unconfined Compression Tests (UCT)
2. Resilient Modulus Tests (M_R)

The UCT specimens were molded in Harvard miniature molds using the manual kneading foot compactor. The target molding conditions were based on field (e.g. Nuclear w-γ) gauge) water content and dry densities measured following compaction of the subgrade at the field test sites and/or compaction tests on treated soils obtained from the cooperating agencies or compaction tests conducted on the field mixed soil samples. Five UCT specimens were prepared for each of the planned curing times (e.g. 1, 3, 7, 14, and 28 days). Three specimens were tested in unconfined compression and two specimens were immersed and soaked for 48 hours then tested in unconfined compression.

The M_R specimens were molded in 4 inch by 8 inch cylindrical mold using static pressure, five layers, and the same target molding conditions used for the UCT's. Two specimens were prepared for each of the planned curing times. No soaked specimens were tested for M_R.

Laboratory-Mixed Soil Samples

Using the dried and processed soil a complete mix design was conducted for each soil and additive used at each field test site using the testing protocol outlined in ASTM D 4609. Treated soil test specimens were prepared, cured, and the following tests were conducted:

1. Soil-Additive pH Test

2. Atterberg Limits (Liquid Limit, Plastic Limit, Plasticity Index)
3. Bar Linear Shrinkage
4. Standard Proctor Compaction Test (with Harvard Miniature Compaction Correlations for UCT Specimens)
5. Unconfined Compression Tests
6. Resilient Modulus Tests

The soil-additive pH test was conducted following ASTM D 6276 protocol using the same soil sample size, reaction time, pH measuring procedure and percent additive selection criteria.

Atterberg Limits were conducted on test specimens prepared by thoroughly mixing properly dried and processed soil and additive at selected percentages, then adding water to 3 to 5 percentage points above the plastic limit of the untreated soil. The wetted soil was covered with plastic wrap, without mixing, and cured for two hours. After curing, the liquid limit and plastic limit were conducted using standard test procedures.

The bar linear shrinkage test specimens were prepared using the same procedure. After curing for two hours, water was added to meet the consistency criteria in the TxDOT test method and the specimen was placed in the molds, air-dried to color change, then oven dried and measured.

The Standard Proctor compaction tests were conducted using a minimum of five test points and individual soil test specimens for each point. The dried and processed soil was thoroughly mixed with the percent additive selected from the pH test, water was added at varying percentages (e.g. increasing water content of 1 ½ to 2% for each test point), then the test specimens were covered with plastic wrap and cured for two hours. After curing, the compaction tests were conducted using standard test procedures. The Harvard miniature compaction correlation was conducted by preparing a treated soil sample at the optimum moisture content, curing for two hours, then molding several Harvard Miniature compacted specimens using varying amounts of impacts of the kneading foot compactor for each of the five soil layers. The number of impacts resulting in a dry density closest to the maximum dry density from the compaction test was selected for molding UCT specimens.

Unconfined Compression Test (UCT) specimens were prepared at optimum moisture content and maximum dry density values determined from compaction tests for the selected additive percentage. Sufficient soil sample to prepare five UCT specimens was weighed and mixed with the selected percent additive. Water was added (2 to 3 percentage points above optimum moisture content), the mixture was covered with plastic wrap and cured for two hours. After curing, the UCT specimens (e.g. Harvard Miniature mold and kneading foot compactor using selected number of impacts) were prepared, individually wrapped, identified, then placed in plastic bags which were placed in thermal chests to minimize temperature changes during specimen curing. Five UCT specimens were prepared and cured for each of the selected curing times (1, 3, 7, 14, 28, 56, days). After curing, three test specimens were tested in unconfined compression and two test specimens were immersed and soaked in distilled water for 48 hours then tested in unconfined compression. In addition to various curing times, UCT specimens were prepared using the same procedures at 3 or 4 different additive percentages (e.g. 2 or 3 additive percentage below and one above the pH determined value). The specimen groups (five UCT specimens) were cured for seven days, tested, and soaked and tested in unconfirmed compression as with the varying time specimens.

Resilent Modulus (M_R) test specimens were prepared at optimum moisture content and maximum dry density values determined from the compaction test for the selected additive percentage. The same sample preparation procedure was used to prepare material for two test specimens. The test specimens were compacted in a 4 in. by 8 in. cylindrical mold using static pressure and five equal layers. The specimens were individually wrapped, identified, stored and cured for the selected curing times (e.g. 1, 3, 7, 14, 28, 56 days). After curing the two specimens were tested using standard testing procedures (AASHTO T307). In addition to the various curing times, M_R specimens were prepared and tested using the same varying additive percentages tested in unconfined compression.

Field Testing Program

The field testing program involved conducting a series of five in situ tests at selected locations over the same 100-foot section of the untreated subgrade and with time after stabilization of the subgrade soils. The field tests (untreated and treated) were conducted within a 3-ft. radius of one another at each of the three selected locations. The in situ test equipment used included:

1. Nuclear w-γ Gauge
2. Stiffness Gauge
3. Dynamic Cone Penetrometer (DCP)
4. Portable Falling Weight Doflectometer (PFWD)
5. PANDA Penetrometer

The Nuclear w-γ gauge measures in-place density (moist and dry) and moisture content and is the most commonly used earthwork quality control method used in current practice. At each of the three test points at the field test site three readings were taken and recorded to monitor in situ conditions, specifically dry density and moisture content.

The stiffness gauge measures the in situ stiffness of the soil based on the soils response to an induced vibration. The basic relationship for stiffness is:

$$K = \frac{P}{S} \square \frac{1.77RE}{\left(1-v^2\right)}$$

K = measured stiffness, MN/m or Kips/in

P = force, MN or Kips

S = deflection, m or ins

E = elastic modulus, MPa or MN/m^2 or Ksi or psi

v = Poisson’s Ratio, dimensionless

R = outside radius of ring foot of stiffness gauge (0.05727m or 2.2547in)

With an assumed Poisson’s Ratio, an elastic modulus can be calculated from the measured stiffness value. At each of the three test points three readings were taken and recorded.

The Dynamic Cone Penetrometer (DCP) test measures the penetration resistance of a 0.785 in dia, 60^0 cone driven into the ground by a 17.6 lb weight dropped 23 inches. The resulting measured penetration data is used to calculate the Dynamic Cone Index

(DCI) which correlates with CBR and resilient modulus. Some of the commonly used correlations include:

$$CBR = \frac{292}{DCI^{1.12}}$$

or

$$\log CBR = 2.465 - 1.12 \log DCI$$

$$M_R(psi) = 1500\ CBR$$

$$M_R(MN/m^2) = 16.25 + \frac{928.24}{DCI}$$

$$M_R(MN/m^2) = 17.6(CBR)^{0.64}$$

$$M_R(psi) = 2555(CBR)^{0.64}$$

$$E(MN/m^2) = 10.34(CBR)$$

At each of the test points one DCP sounding was conducted to a depth of at least 1.5 to 2 ft.

The Portable Falling Weight Deflectometer (PFWD) measures the deflection of a 30 cm dia. by 2 cm thick plate in response to a dynamic force caused by a 10 Kg weight dropped 69cm. The calculated result is a dynamic elastic modulus similar to that calculated from the deflection basin of a full-scale FWD. At each of the three test points three PFWD tests were conducted.

The PANDA penetrometer measures the penetration resistance (in units of stress) of a 0.625 in (2cm^2) dia. 60^o cone driven into the ground with a 3.65 lbs dead-blow hammer. The hand-held data collector unit continually monitors the penetration per blow, total penetration, and penetration resistance. At each of the three test points, one PANDA penetration sounding was conducted to a depth of 1.5 to 2 ft.

Chapter 4

RESEARCH RESULTS

The laboratory and field testing programs resulted in a large volume of data. In order to accommodate the large about of data, summary tables were prepared for several categories of data:

1. UCS with curing time for field mixed samples
2. UCS with curing time for laboratory mixed samples
3. UCS with percent additive for laboratory mixed samples
4. M_R with curing time for field mixed samples
5. M_R with curing time for laboratory mixed samples
6. M_R with percent additive for laboratory mixed samples
7. Field data summary for nuclear w-γ gauge and stiffness
8. Field data summary for portable FWD, DCP, and PANDA Pentrometer.

Each of the 8 summary tables is presented in the appendices attached to this report:

1. Appendix 1 --- Oakdale Dr. – North, Enid, OK
2. Appendix 2 --- Oakdale Dr. – South, Enid, OK
3. Appendix 3 --- U.S. 62 – Anadarko, OK
4. Appendix 4 --- 15th Street – Perry, OK
5. Appendix 5 --- Country Club Road – Payne County, OK

The balance of this chapter will present preliminary data plots and related discussion to support evaluations discussed in Chapter 5.

Laboratory Data

In place soil properties, untreated soil classification properties, and compaction test results are shown in Table 4.1. The five field test sites include soil types ranging from A-2-4 to A-4 to A-6 categories with PI's ranging from NP to about 22. In place moisture contents and dry densities are consistent with the range of soil types, i.e. lower for non-plastic soils and higher for the more plastic soils. Compaction test results (e.g. dry density) show a range of typical values also consistent with soil types, i.e. higher for non-plastic soils and lower for more plastic soils.

Additive percentage based on pH test (ASTM D 6276) results were used for laboratory mix design testing. Figure 4.1a, 4.1b, 4.1c, 4.1d, and 4.1e show the results of the soil-additive pH tests for each of the five field test sites.

Table 4.1

Inplace Dry Density, Water Content, Untreated

Classification and Compaction Test Results

		Nuclear w-γ			***Atterberg Limits***				***Soil Classification***		***Standard Proctor Compaction***	
Site	**w_{Nat} % (Lab)**	**w %**	**γ_{dry} pcf**	**%-200 %**	**LL %**	**PL %**	**PI %**	**BLS %**	**AASHTO**	**USCS**	**w_{opt} %**	**$\gamma_{dry-max}$ pcf**
Oakdale Dr.- North, Enid	14.3	13.8	130.0	42.9	24.3	13.5	10.8	7.0	A-6 (1)	SC	12.8	115.1
Oakdale Dr.- South, Enid	5.1	8.5	126.2	21.7	-	-	NP	0.4	A-2-4	SM	10.3	117.2
US 62- Anadarko	6.2	7.0	117.1	55.9	-	-	NP	1.4	A-4 (0)	ML	13.3	112.4
15th St- Perry	18.1	22.0	103.7	76.8	40.0	18.0	22.0	18.2	A-6 (16)	CL	17.8	106.1
Country Club Rd – Payne Co.	10.7	13.9	111.8	53.0	24.1	14.3	9.8	9.8	A-4 (2)	CL	13.6	116.4

All test results are the average of duplicate tests.

Figure 4.1a
Soil - CKD pH Test
for Oakdale Dr. - North, Enid, Ok

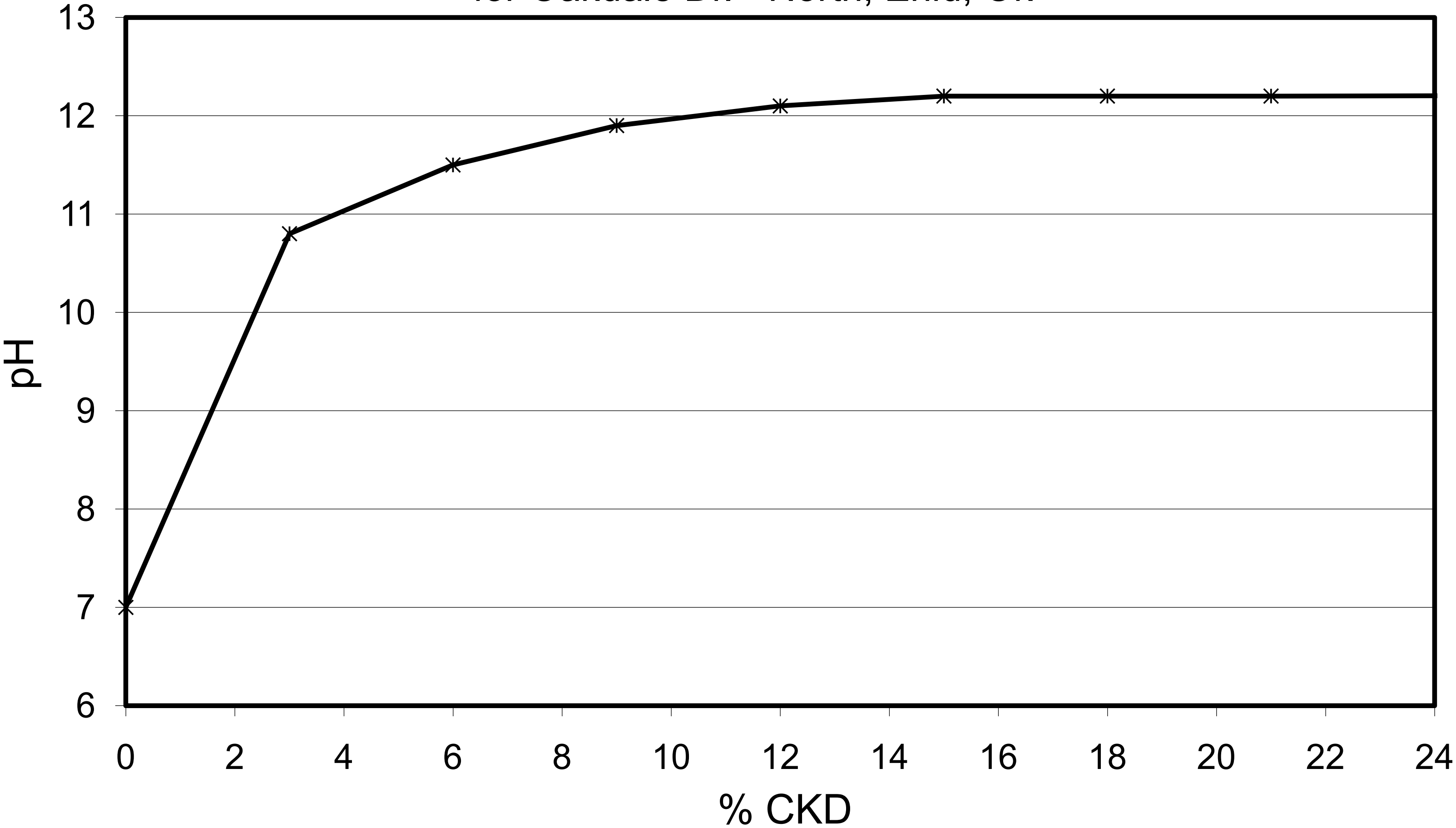


Figure 4.1b
Soil - CKD pH Test
for Oakdale Dr. - South, Enid, Ok

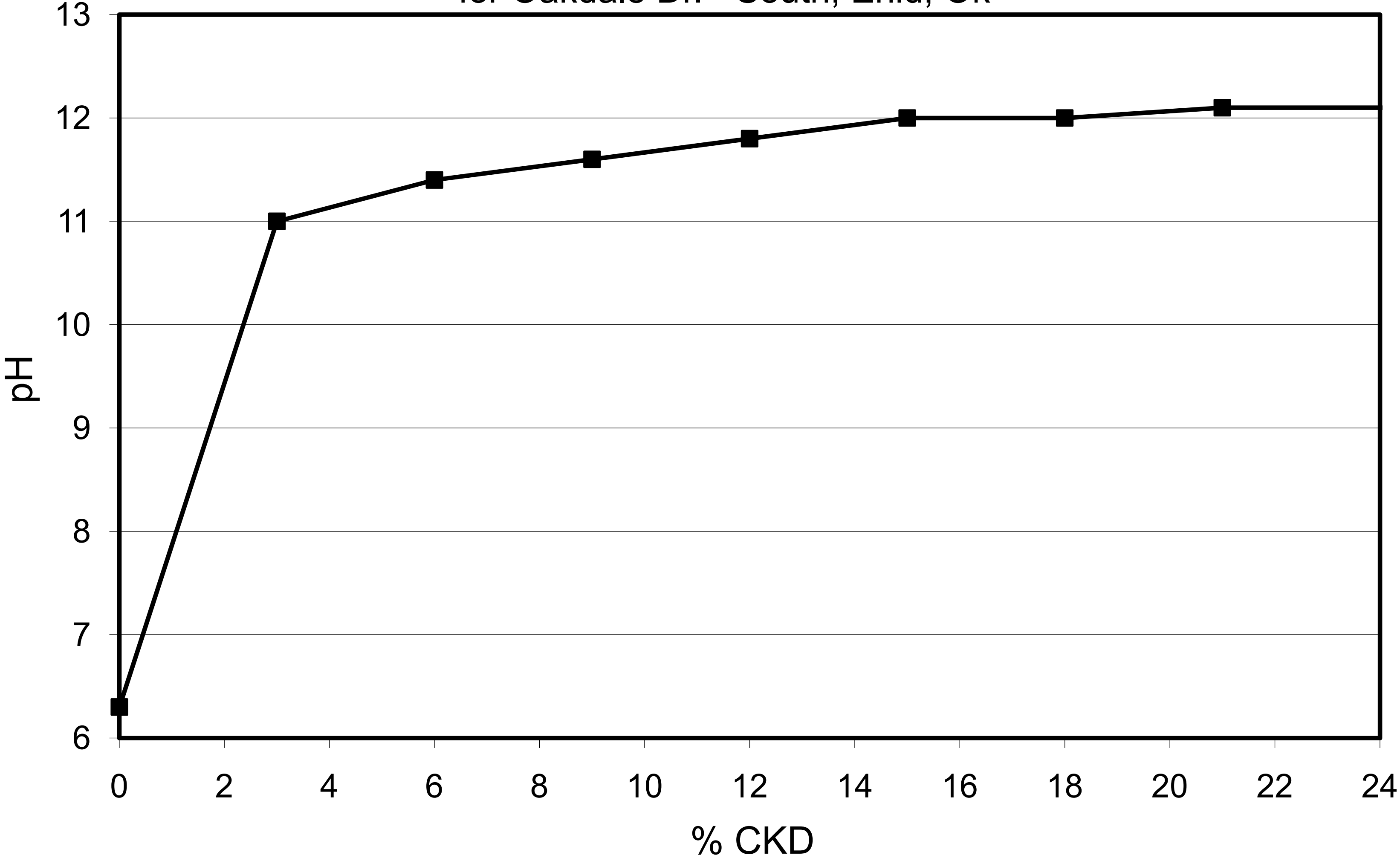


Figure 4.1c
Soil - Fly Ash pH Test
for U.S. 62, Anadarko, Ok

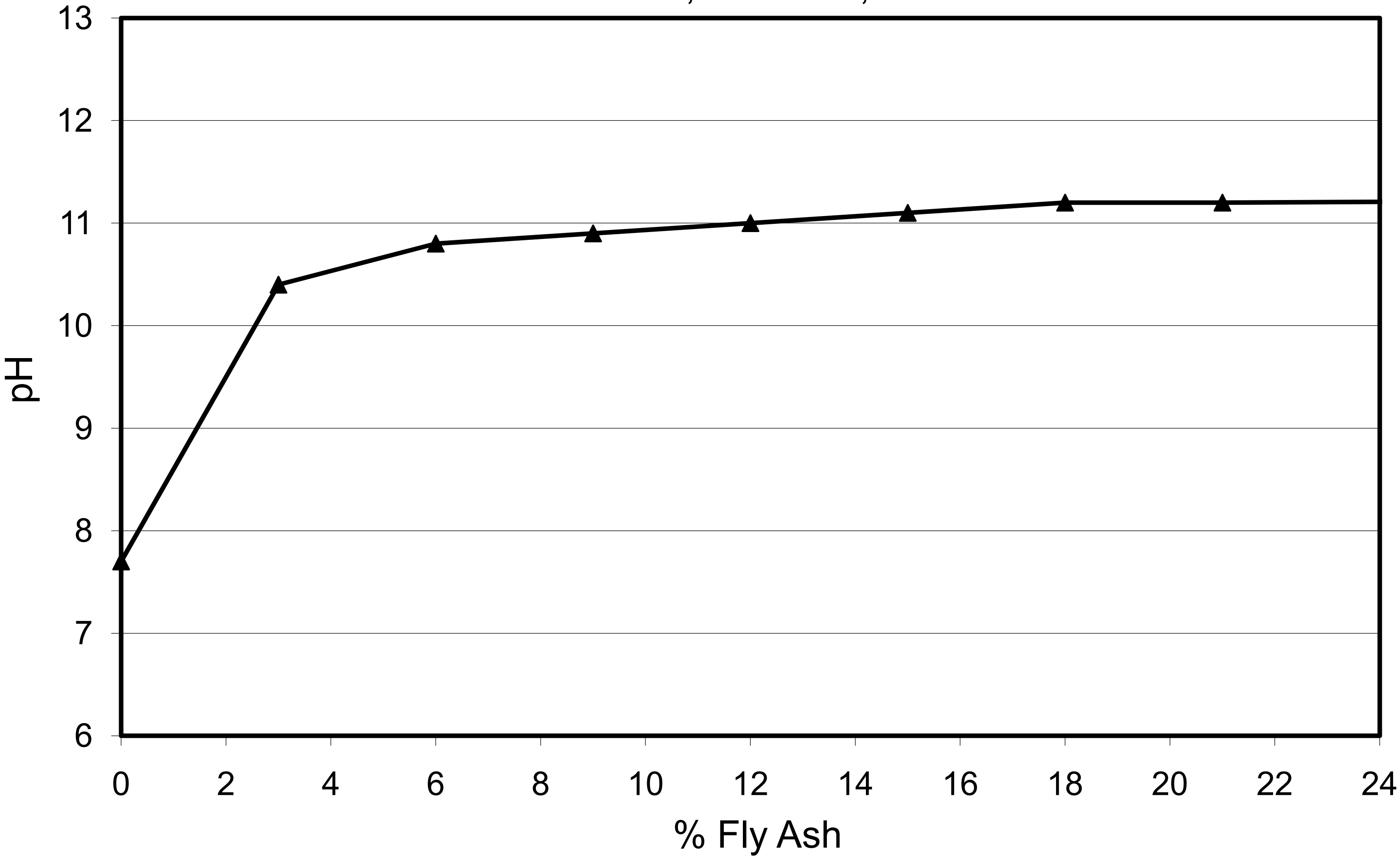


Figure 4.1d
Soil - Fly Ash pH Test
for 15th Street, Perry, Ok

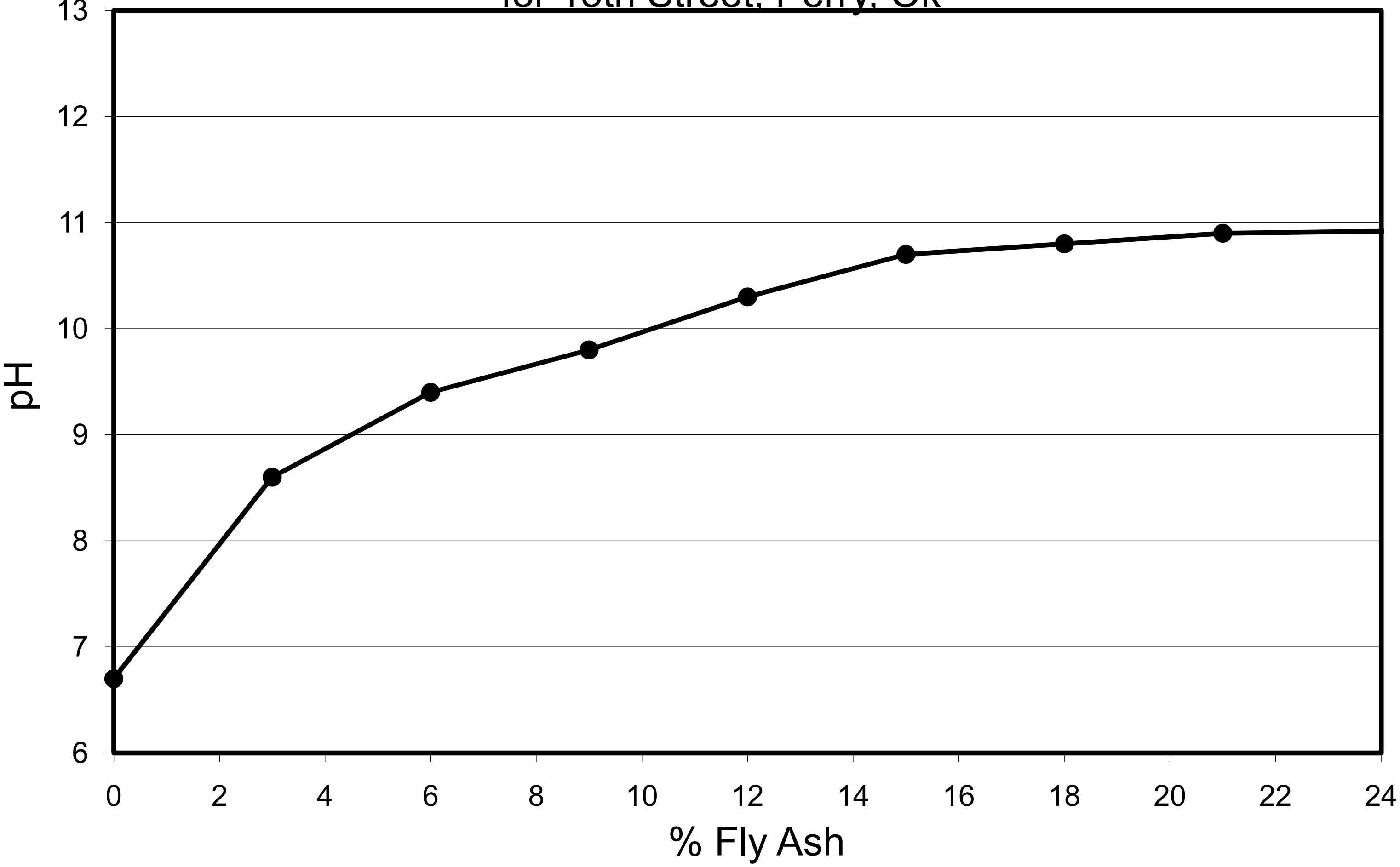


Figure 4.1e
Soil - Fly Ash pH Test
for Country Club Road, Payne County, Ok

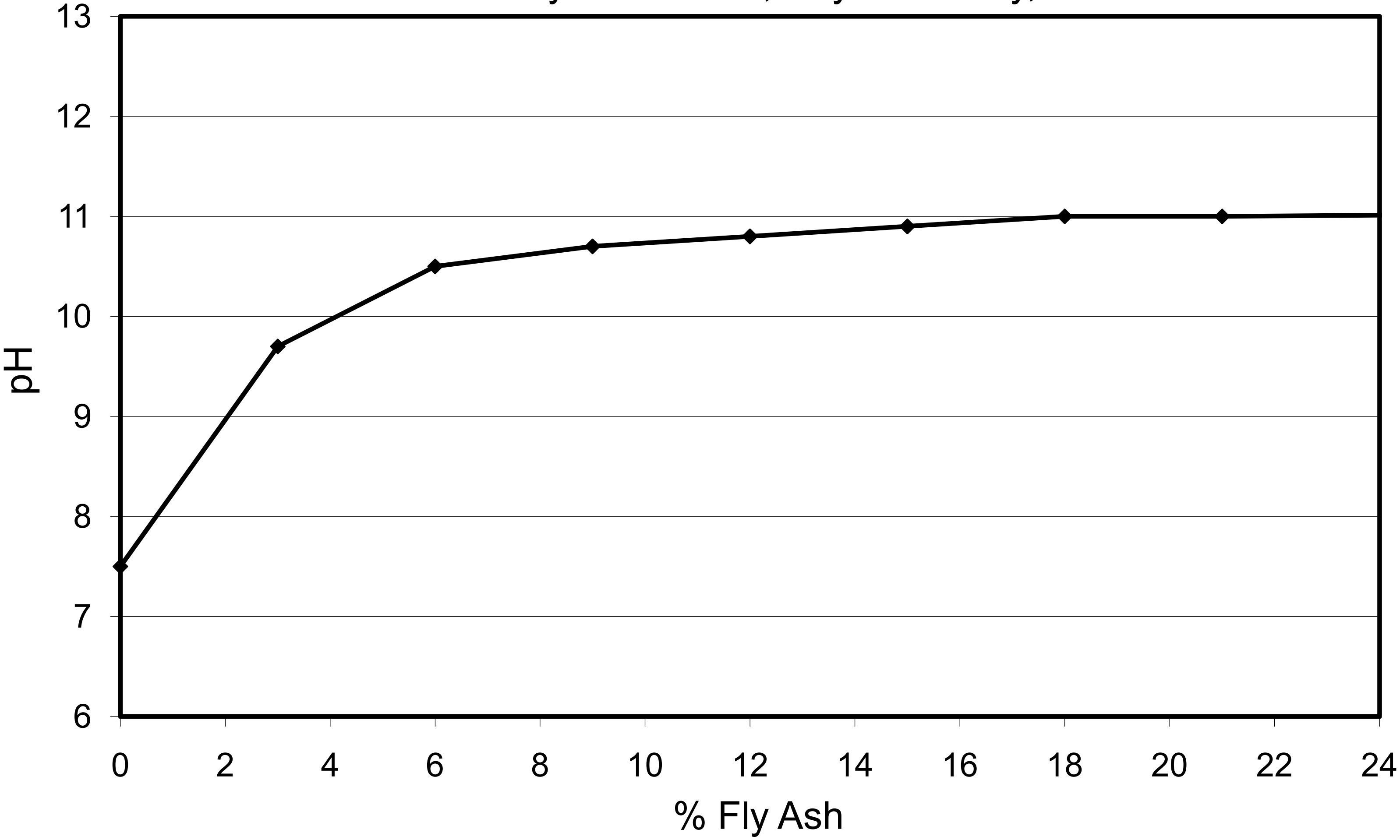


Table 4.2 summarizes the influence of percent additive used on plasticity and compaction properties. As expected, the additives used reduced the PI for the more plastic soils and had no effect on the non-plastic soils. Compaction Test results showed no consistent influence on dry density or moisture content.

Unconfined Compression Strength

Figures 4.2a, 4.2b, and 4.2c show UCS with curing time for field mixed samples, UCS with curing time for laboratory mixed samples, and UCS with percent CKD for subgrade soils from Oakdale Dr. – North, Enid, respectively. Also shown on figures 4.2a and 4.2b are the UCS with curing time for soaked (48 hours) test specimens which is a requirement for ASTM D 4609. As expected, the soaked UCS is lower than the unsoaked and difference between the curves is greater for the field mixed samples. The purpose of the soaked UCS protocol is an additional confirmation of the influence of additives on improving soil strength (e.g. kind of a worst case scenario for the treated soil). No additional discussion of the soaked UCS relationships will be included in this chapter. UCS develops rapidly in the first seven days and then increases at a lower rate after seven days for both field and laboratory mixed samples. The small reduction in UCS for the field mixed samples is probably related to experimental (testing) variability. UCS versus % CKD confirms the generally accepted knowledge that at some percent additive the amount of strength improvement levels or drops off. In other words, typical additive selection criteria require the lowest percentage necessary to achieve desired improvement or the percent additive beyond which no significant improvement occurs. The UCS began leveling at 14% CKD which corresponded to the soil-CKD pH test results. UCS values at 7 and 28 days were 116.4 psi and 127.8 psi, respectively, for field laboratory mixed samples. Laboratory mixed samples exhibited UCS values approximately twice as large as the field mixed samples, which should come as no surprise, primarily because difference in such items as preparation, additive mixing, and specimen preparation process.

Table 4.2

Classification and Compaction Test Results for Treated Soil Samples

			Treated Soil Samples Atterberg Limits					Standard Proctor Compaction	
Site	Additive Used	% Additive From pH Test (ASTM D 6276)	% Additive	LL %	PL %	PI %	BLS %	w_{Nat} %	$\gamma_{dry\text{-}max}$ pcf
Oakdale Dr. – North, Enid	Cement Kiln Dust (CKD)	14%	0	24.3	13.5	10.8	7.0		
			6	25.8	18.8	7.0	3.1		
			10	23.8	20.5	3.3	2.8		
			14	22.2	20.1	2.1	0.2	10.7	111.7
Oakdale Dr. – South, Enid	Cement Kiln Dust (CKD)	12%	0	-	-	NP	0.4		
			4	-	-	NP	1.1		
			8	-	-	NP	0.6		
			12	-	-	NP	0.8	10.2	117.9
U.S. 62, Anadarko	Fly Ash (C)	15%	0	-	-	NP	1.4		
			5	-	-	NP	1.9		
			10	-	-	NP	1.8		
			15	-	-	NP	1.7	11.6	115.4
15th St., Perry	Fly Ash (C)	15%	0	40.0	18.0	22.0	18.2		
			5	43.8	18.4	25.4	11.1		
			10	39.2	21.1	18.1	9.7		
			15	37.0	21.8	15.2	5.9	15.4	106.9
Country Club Rd, Payne County	Fly Ash (C)	16%	0	24.1	14.3	9.8	9.8		
			4	25.6	13.6	12.0	5.0		
			8	24.8	15.5	9.3	4.7		
			12	26.0	15.5	10.5	4.5		
			16	24.8	15.9	8.9	3.7	11.9	118.5

Figure 4.2a
Unconfined Compression Strength versus Curing Time
for Oakdale Dr. - North, Enid, Ok at 12% CKD
(FS refers to a field mixed samples)

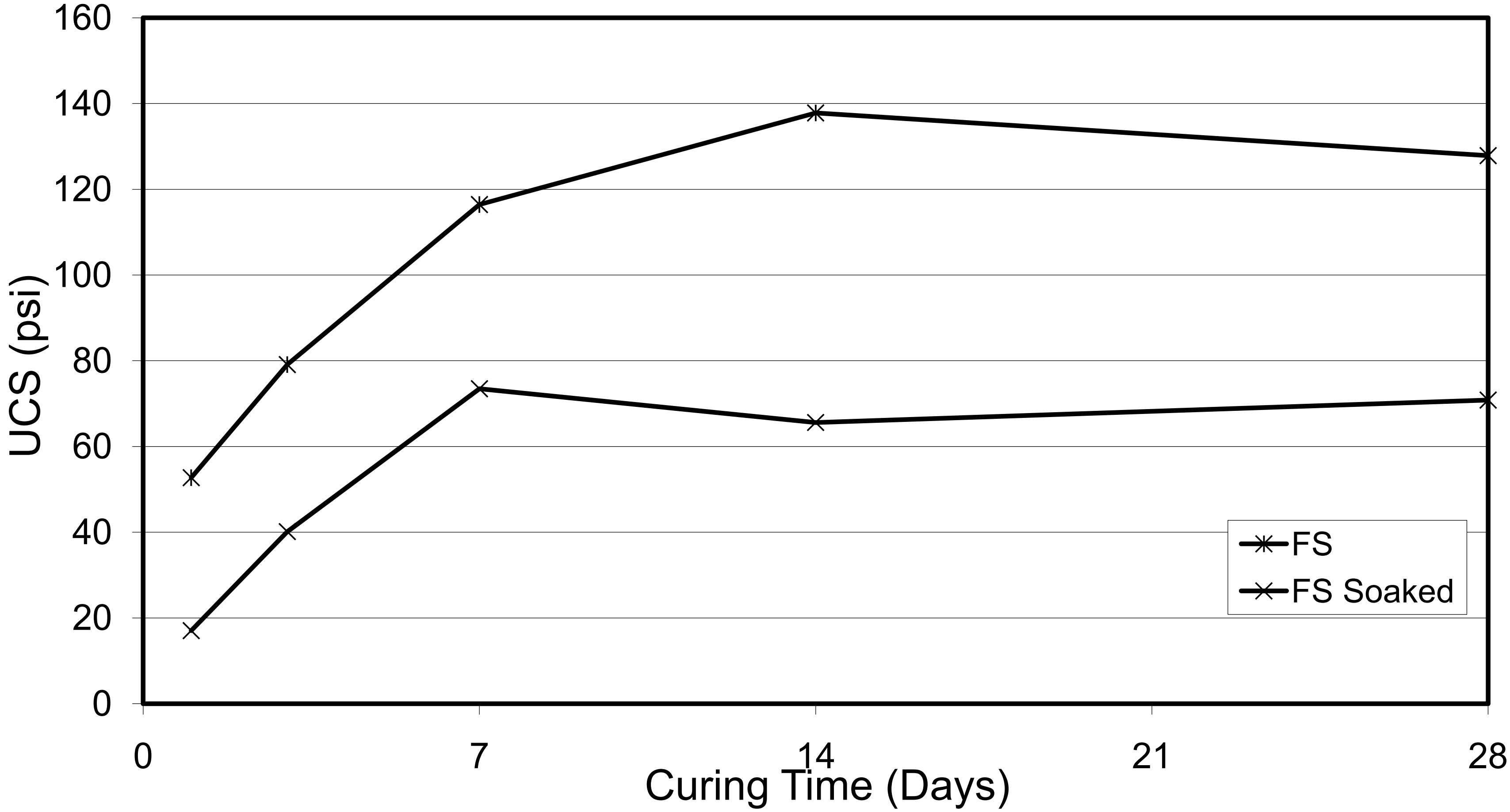


Figure 4.2b
Unconfined Compressive Strength versus Curing Time
for Oakdale Dr. - North, Enid, Ok at 14% CKD
(LS refers to laboratory mixed samples)

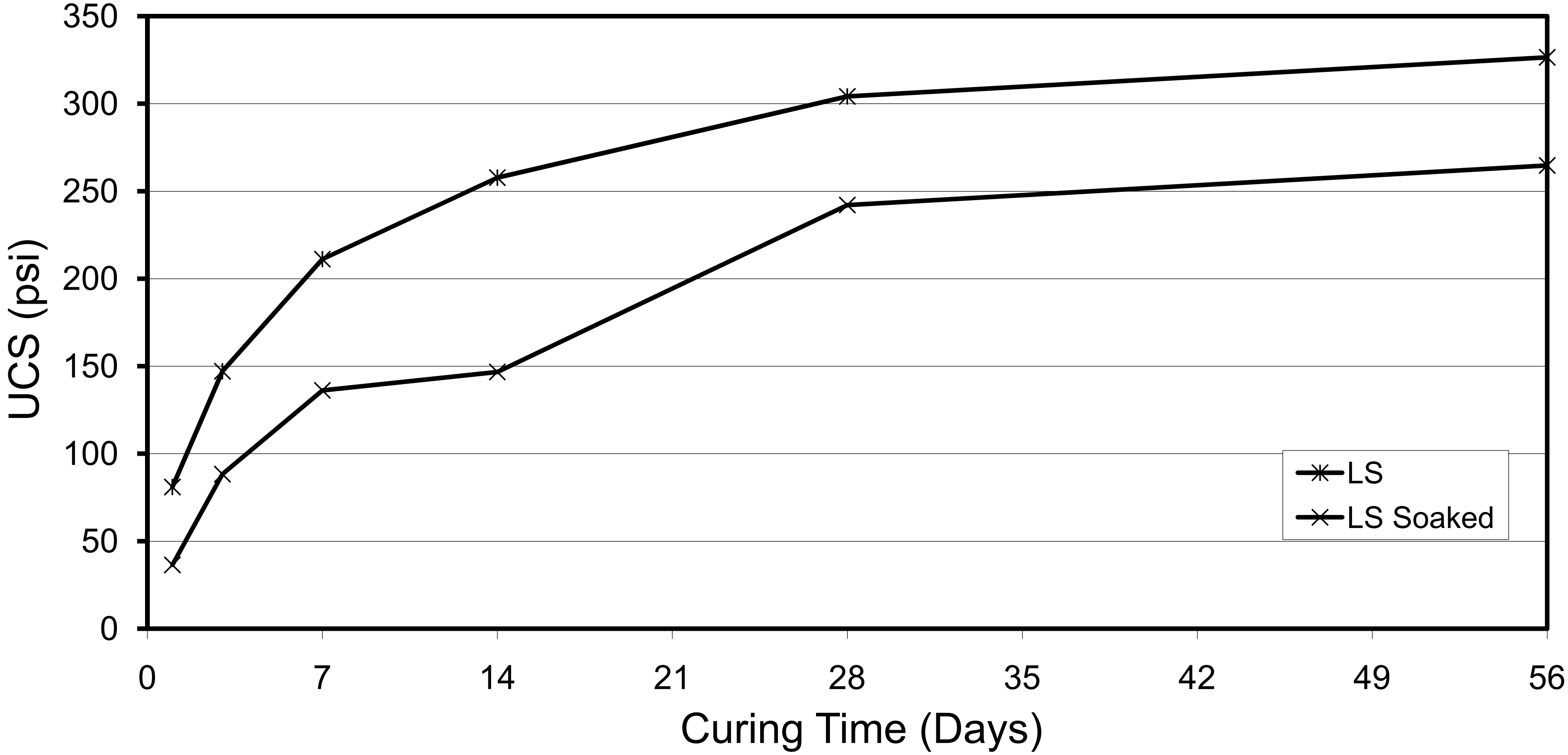
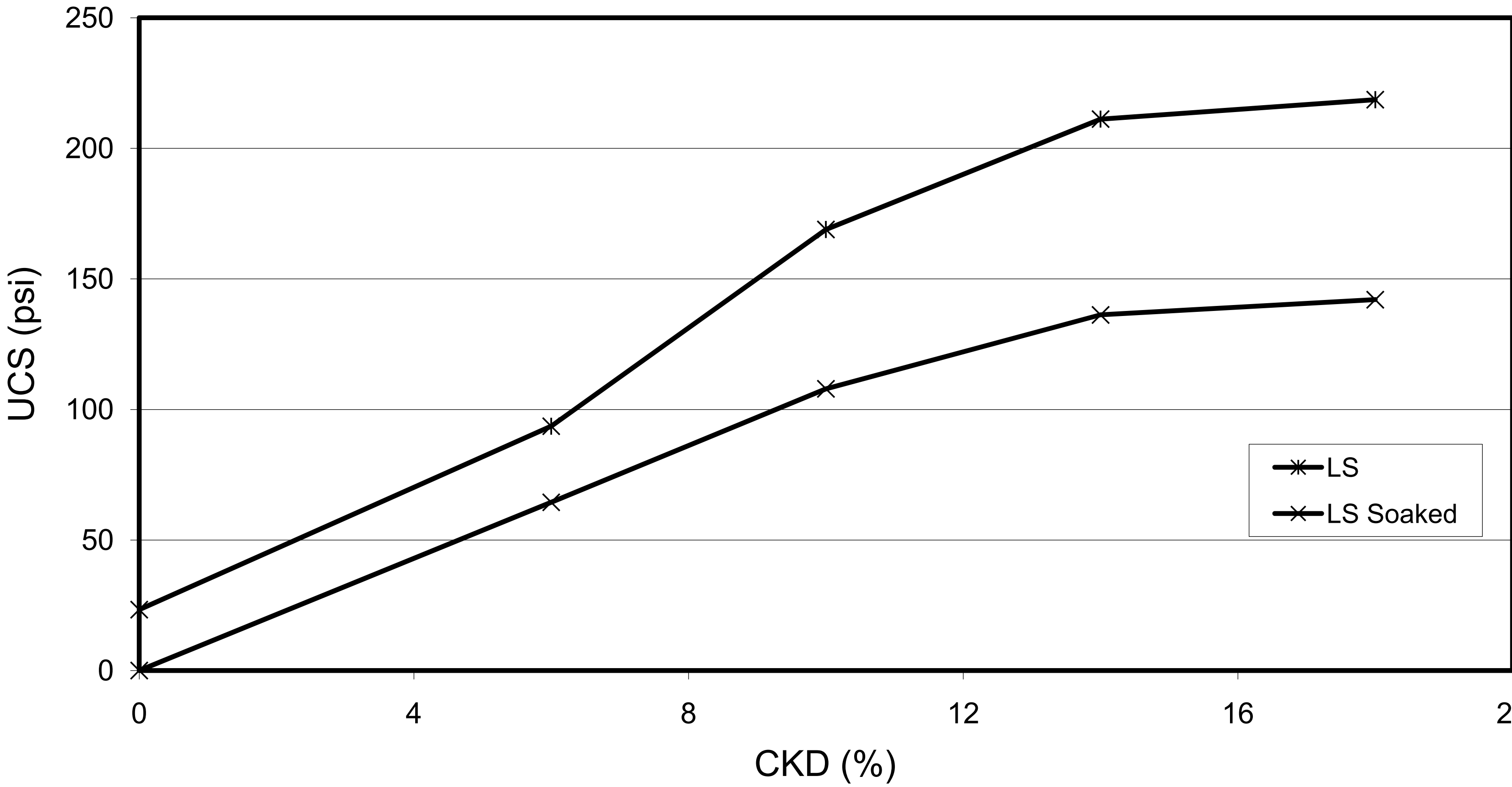


Figure 4.2c
Unconfined Compressive Strength versus Percent Additive
for Oakdale Dr. - North, Enid, Ok at a Curing Time of 7 Days
(LS refers to laboratory mixed samples)



Figures 4.3a, 4.3b, and 4.3c show UCS with curing time for field mixed samples, UCS with curing time for laboratory mixed samples, and UCS with percent CKD for subgrade soils from Oakdale Dr. – South, Enid, OK, respectively. For the field mixed samples, the UCS developed rapidly to 7 days then developed at a lower rate. For the laboratory mixed samples, the rapid rate of UCS development continued throughout 28 days then reduced. UCS versus % CKD exhibited a peak at 16% CKD which was higher that either the soil-CKD pH test results or the % CKD selected and used in the field. UCS values at 7 and 28 days were 61.4 psi and 88.8 psi, respectively, for field mixed samples and 76.2 psi and 163.0 psi, respectively, for laboratory mixed samples. Seven day UCS values were similar, but the laboratory mixed 28 day UCS values were approximately twice the field mixed values.

Figures 4.4a, 4.4b, and 4.4c show UCS with curing time for field mixed samples, UCS with curing time for laboratory mixed samples, and UCS with percent fly ash for subgrade soils from U.S. 62, Anadarko, respectively. The rate of increase of UCS with curing time was more gradual for both field and laboratory mixed samples. UCS with % fly ash showed no indication of leveling through the percentages tested. The field mixed % fly ash (e.g. 12%) was based on OHD L-50, the laboratory mixed % fly ash (e.g. 15%) was based on results of soil-fly ash pH test. Neither of which appear to indicate sufficient additive to meet the generally accepted strength improvement criteria. UCS values at 7 and 28 days were 46.3 psi and 61.7 psi, respectively, for field mixed samples and 51.5 psi and 53.2 psi, respectively, for laboratory mixed samples. The difference between field and laboratory mixed samples was minimal and the 28 day field mixed UCS was higher than the laboratory mixed value.

Figure 4.3a
Unconfined Compression Strength versus Curing Time
for Oakdale Dr. - South, Enid, Ok at 12% CKD
(FS refers to a field mixed samples)

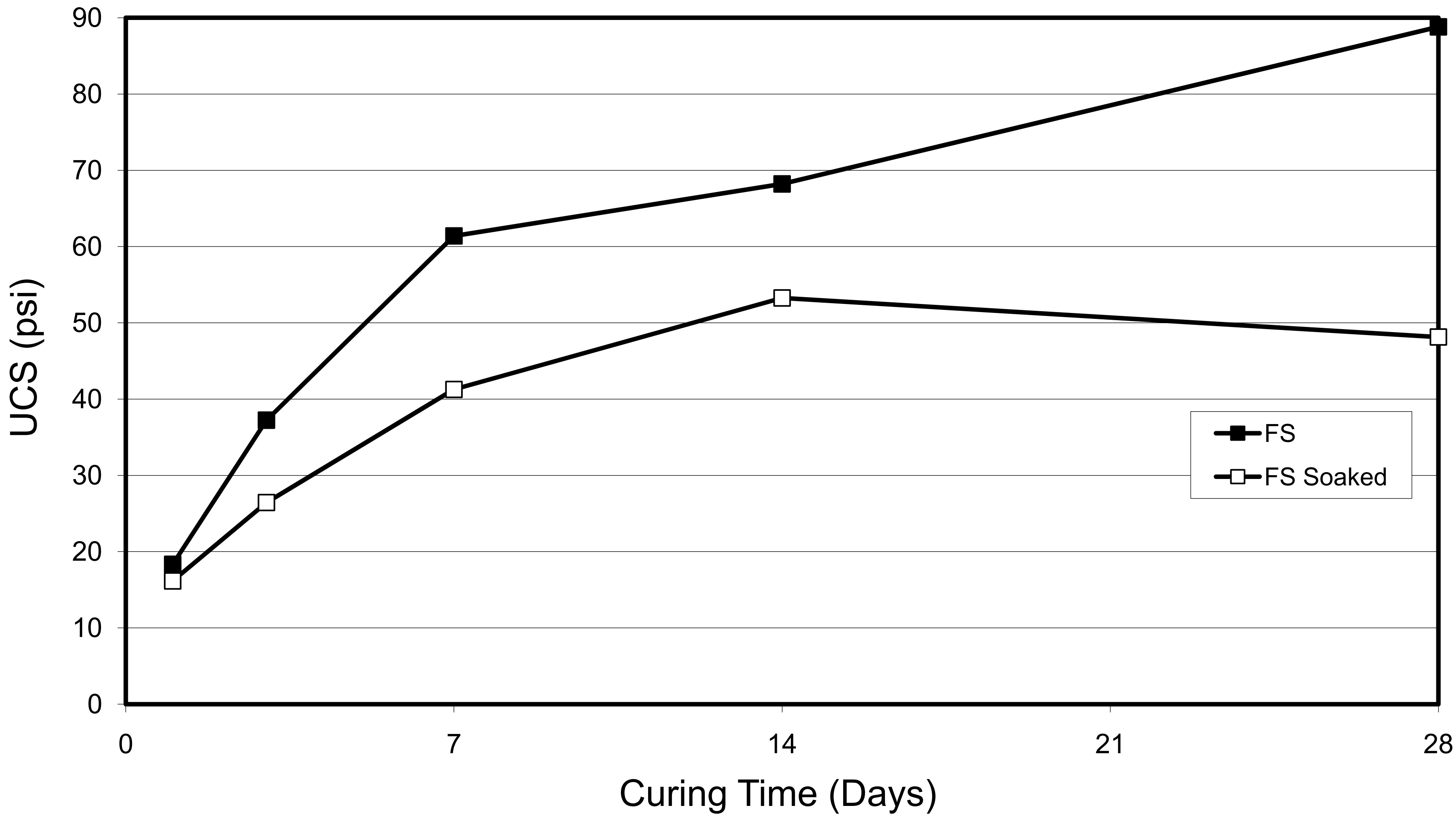


Figure 4.3b
Unconfined Compression Strength versus Curing Time
for Oakdale Dr. - South, Enid, Ok at 12% CKD
(LS refers to a laboratory mixed samples)

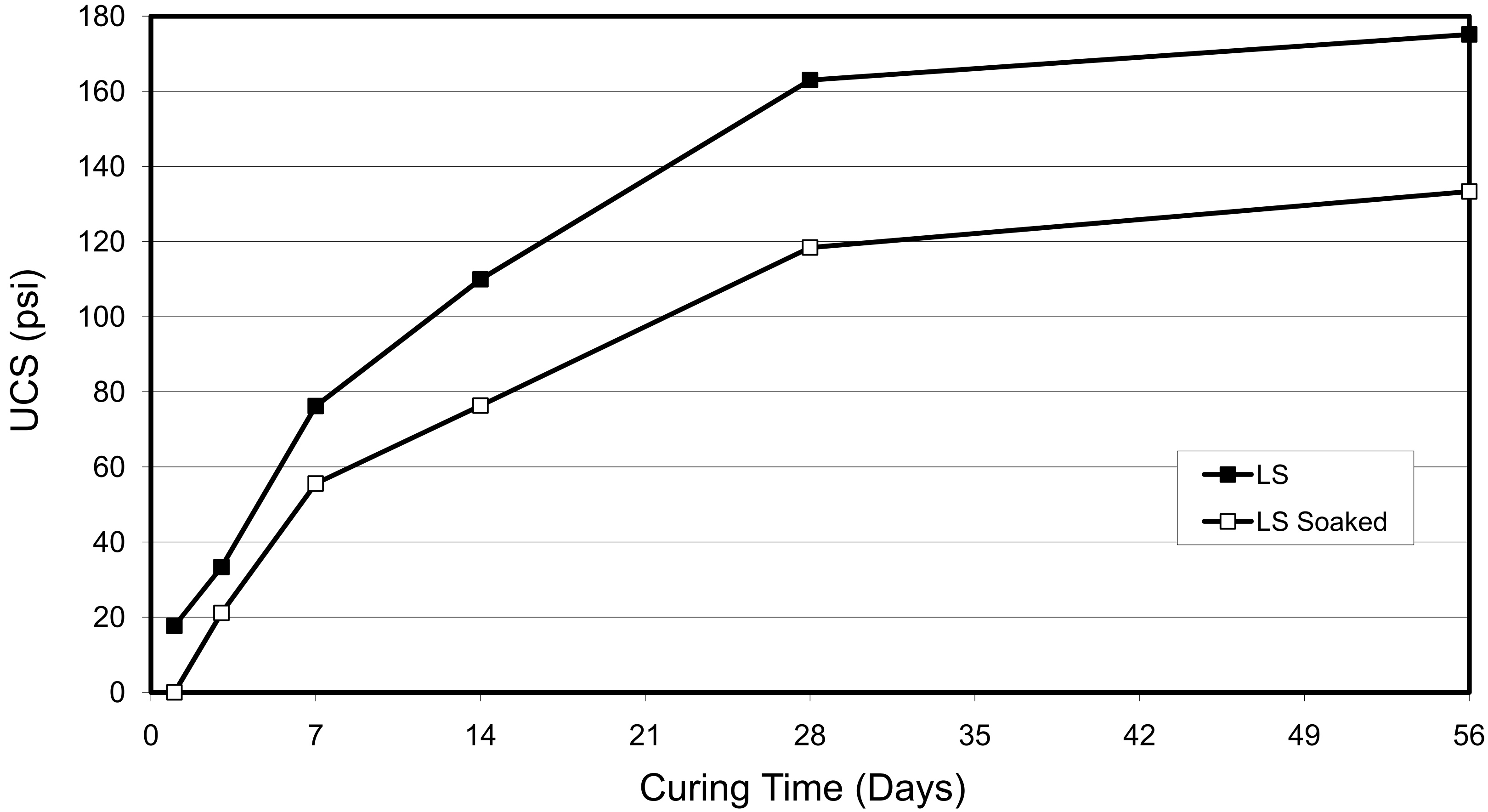


Figure 4.3c
Unconfined Compressive Strength versus Percent Additive
for Oakdale Dr. - South, Enid Ok at a Curing Time of 7 Days
(LS refers to laboratory mixed samples)

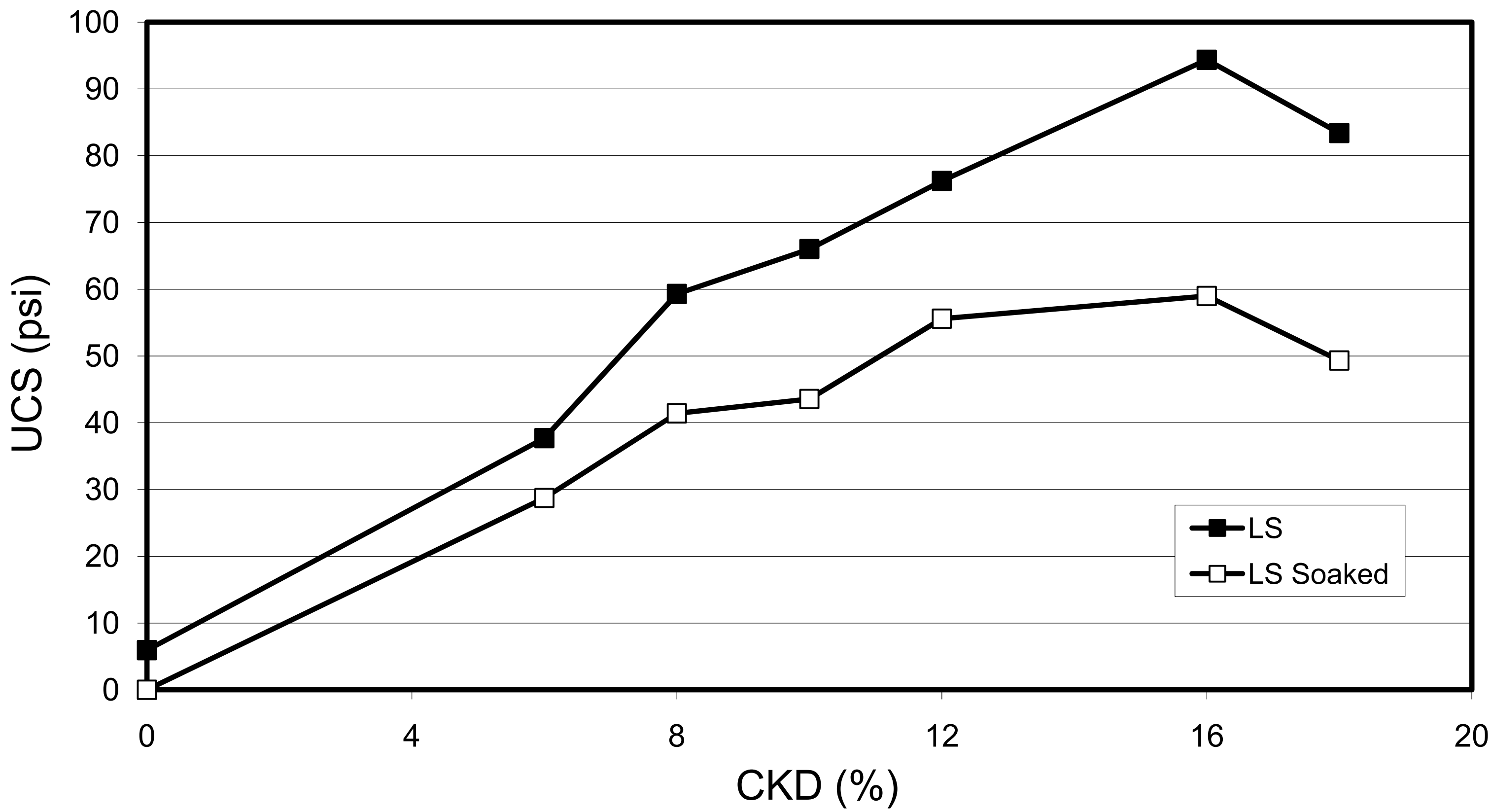


Figure 4.4a
Unconfined Compression Strength versus Curing Time
for U.S. 62, Anadarko, Ok at 12% Fly Ash
(FS refers to a field mixed samples)

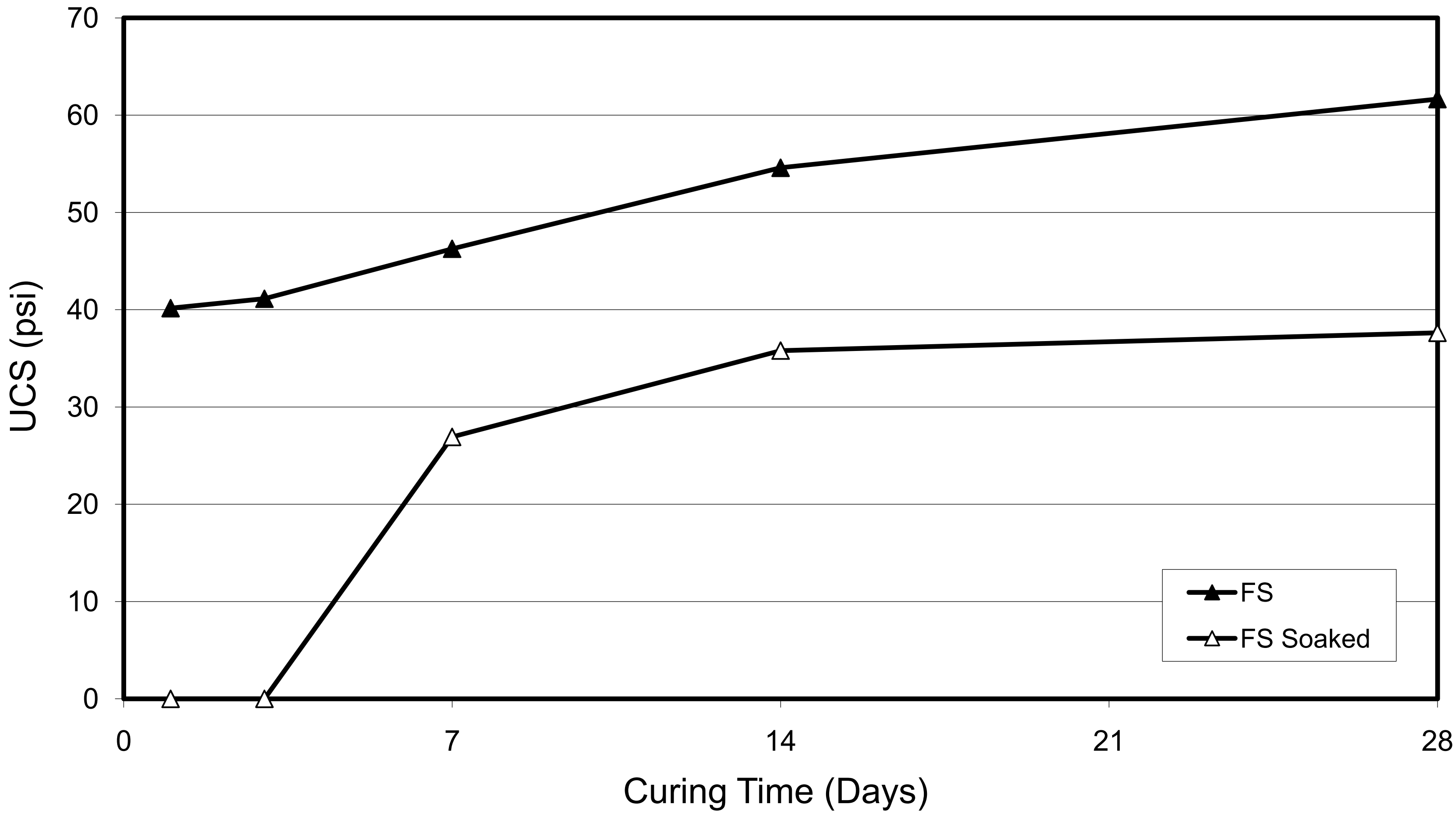


Figure 4.4b
Unconfined Compression Strength versus Curing Time
for U.S. 62, Anadarko, Ok at 15% Fly Ash
(LS refers to a laboratory mixed samples)

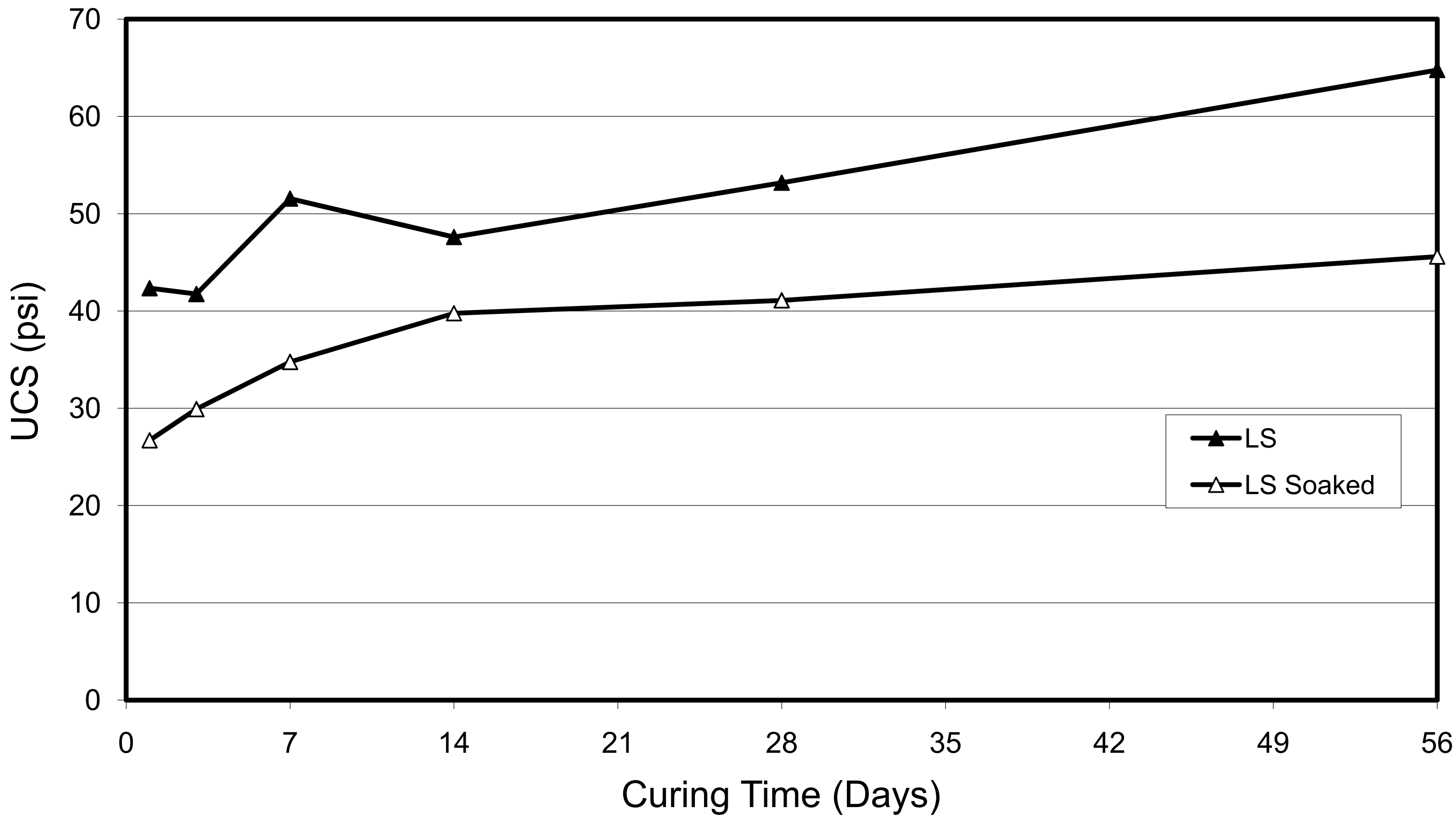
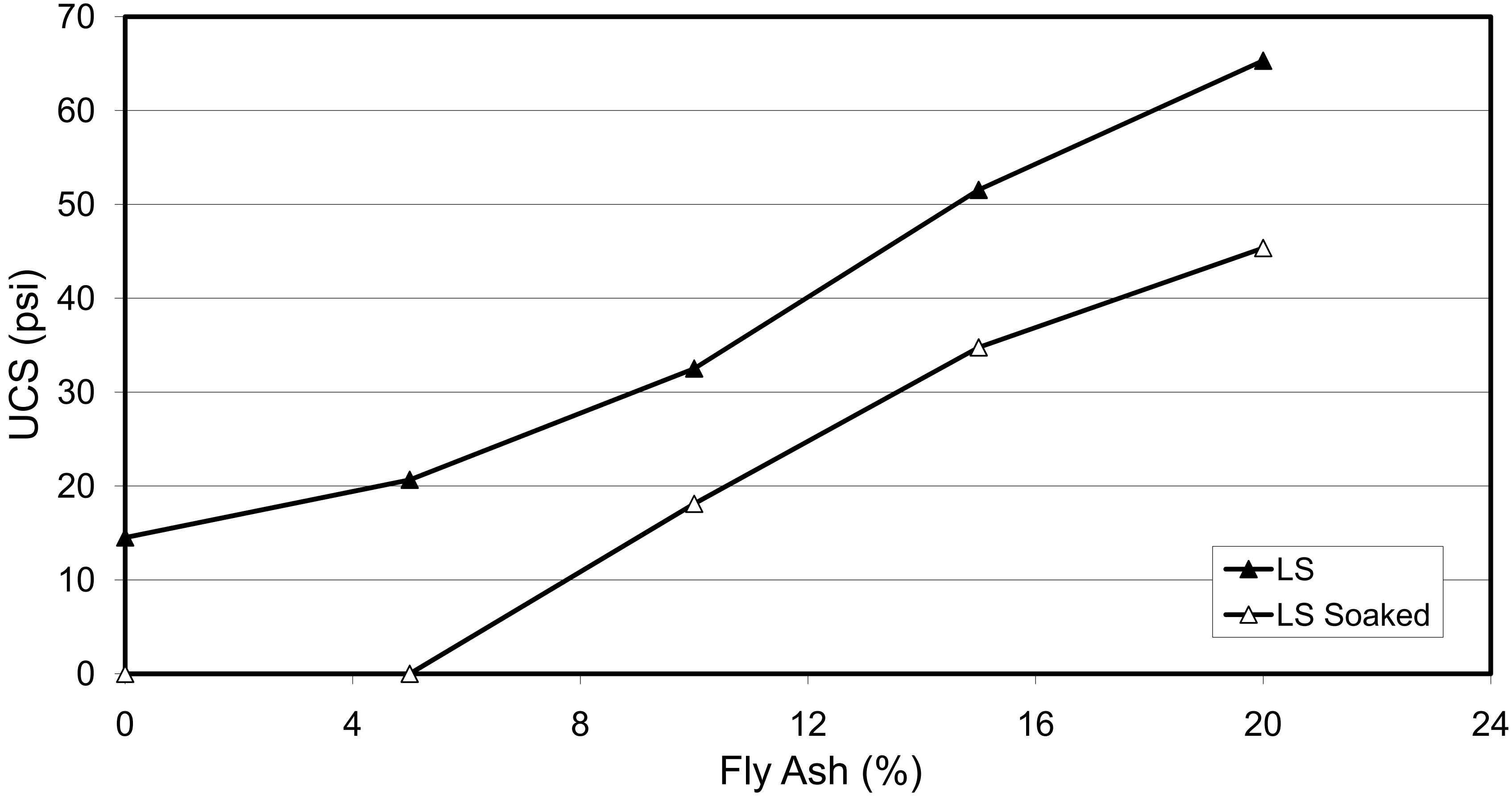


Figure 4.4c
Unconfined Compressive Strength versus Percent Additive
for U.S. 62, Anadarko, Ok at a Curing Time of 7 Days
(LS refers to laboratory mixed samples)



Figures 4.5a, 4.5b, and 4.5c show UCS with curing time for field mixed samples, UCS with curing time for laboratory mixed samples, and UCS with percent fly ash for subgrade soils from 15th Street, Perry, respectively. The rate of increase of UCS was somewhat greater up to 7 days for field mixed samples and significantly greater up to 7 days for laboratory mixed samples. UCS with % fly ash showed a leveling off at 16% fly ash which roughly corresponded to the 15% fly ash determined from the soil-fly ash pH test (e.g. laboratory mixed samples). The 12% fly ash used in the field mixed samples was determined from ODH L-50. UCS values at 7 and 28 days were 51.9 psi and 64.7 psi, respectively, for field mixed samples and 98.0 psi and 112.2 psi, respectively, for laboratory mixed samples. Again, laboratory mixed UCS values were roughly twice the field mixed values.

Figures 4.6a, 4.6b, and 4.6c show UCS with curing time for field mixed samples, UCS with curing time for laboratory mixed samples, and UCS with percent fly ash for subgrade soils for Country Club Road, Payne County, respectively. It should be noted that the unusually high percent fly ash used for the field mixed samples was the result of choice of construction method used by the county road crew. Typically, the county road crew applies on truck load of fly ash (≈ 50000 lbs) to 150 feet of roadway, 28 to 30 feet wide and mixes it with a rolling mixer to a depth of approximately 8 inches. This would typically result in an application rate of 15%. Unfortunately at the time of construction the rolling mixer was not available (broken down) so the county crew used motor graders to rip the subgrade and mix the fly ash and soil by rolling windrows back and forth. The soil and fly ash were mixed well, but the effective depth of the application was reduced to approximately 4 inches. This resulted in an application rate of more than 30%, which makes comparisons between field and laboratory mixed samples difficult. Specifically, the UCS values at 7 and 28 days were 178.4 psi and 159.6 psi, respectively, for field mixed samples and 89.4 psi and 119.1 psi, respectively, for laboratory mixed samples, which is a reversal of the field to laboratory trend noted at the other sites. The results may be flawed because of construction choices, but the laboratory trends will be useful. UCS with % fly ash showed no tendency to level or drop off at the percentages tested.

Figure 4.5a
Unconfined Compression Strength versus Curing Time
for 15th Street, Perry, Ok, at 12% Fly Ash
(FS refers to a field mixed samples)

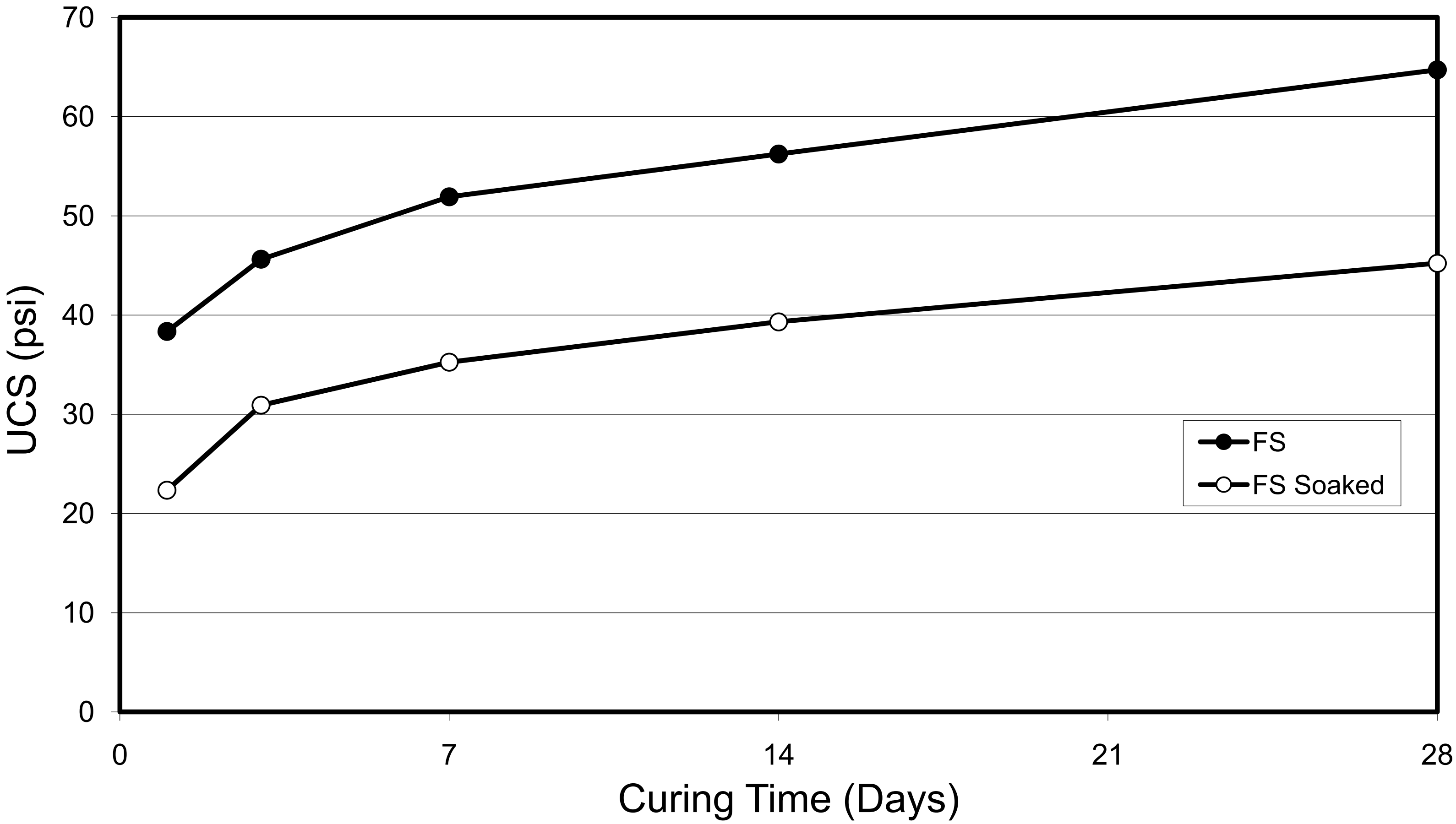


Figure 4.5b
Unconfined Compression Strength versus Curing Time
for 15th Street, Perry, Ok at 15% Fly Ash
(LS refers to a laboratory mixed samples)

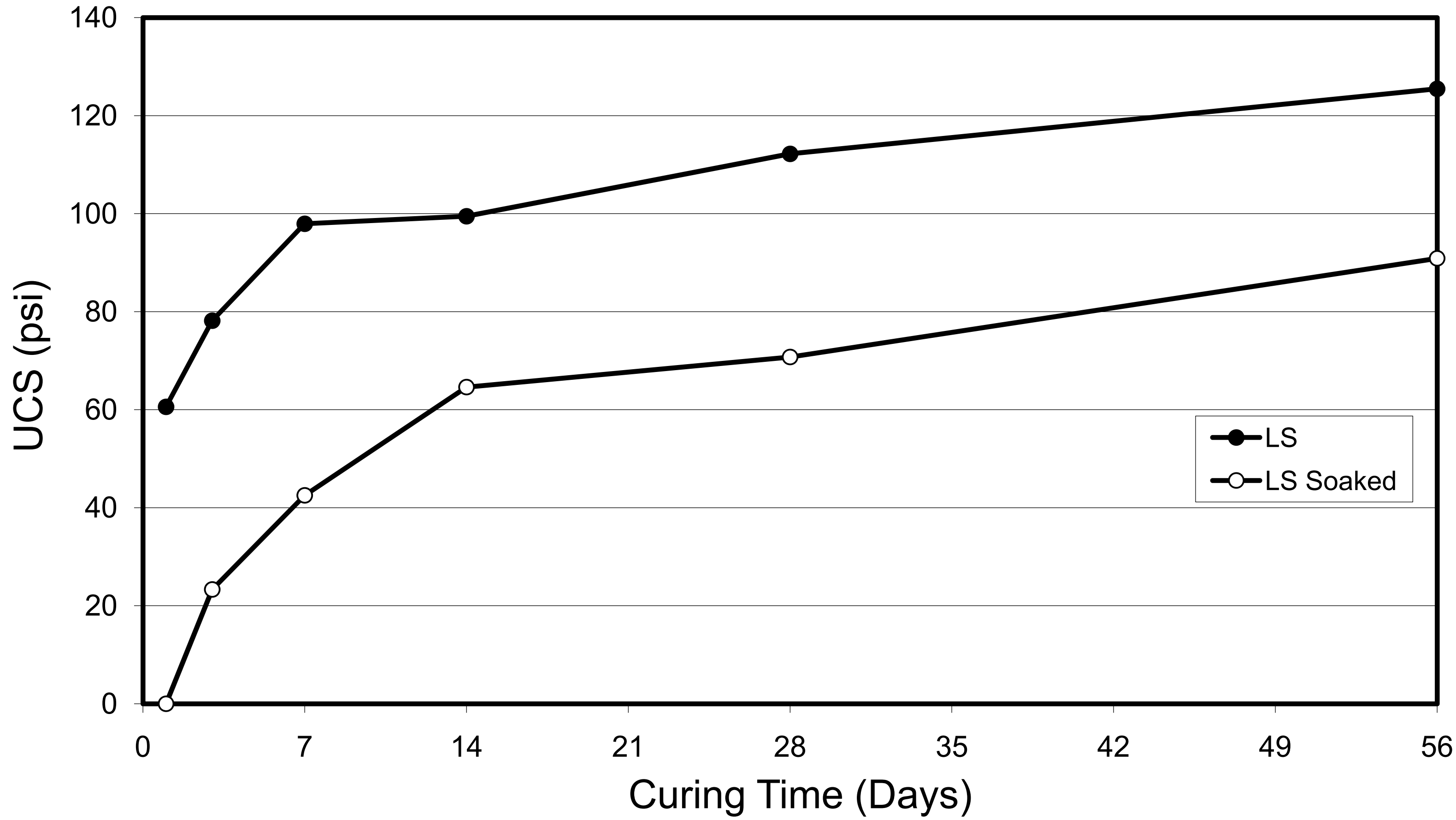


Figure 4.5c
Unconfined Compressive Strength versus Percent Additive
for 15th Street, Perry, Ok at a Curing Time of 7 Days
(LS refers to laboratory mixed samples)

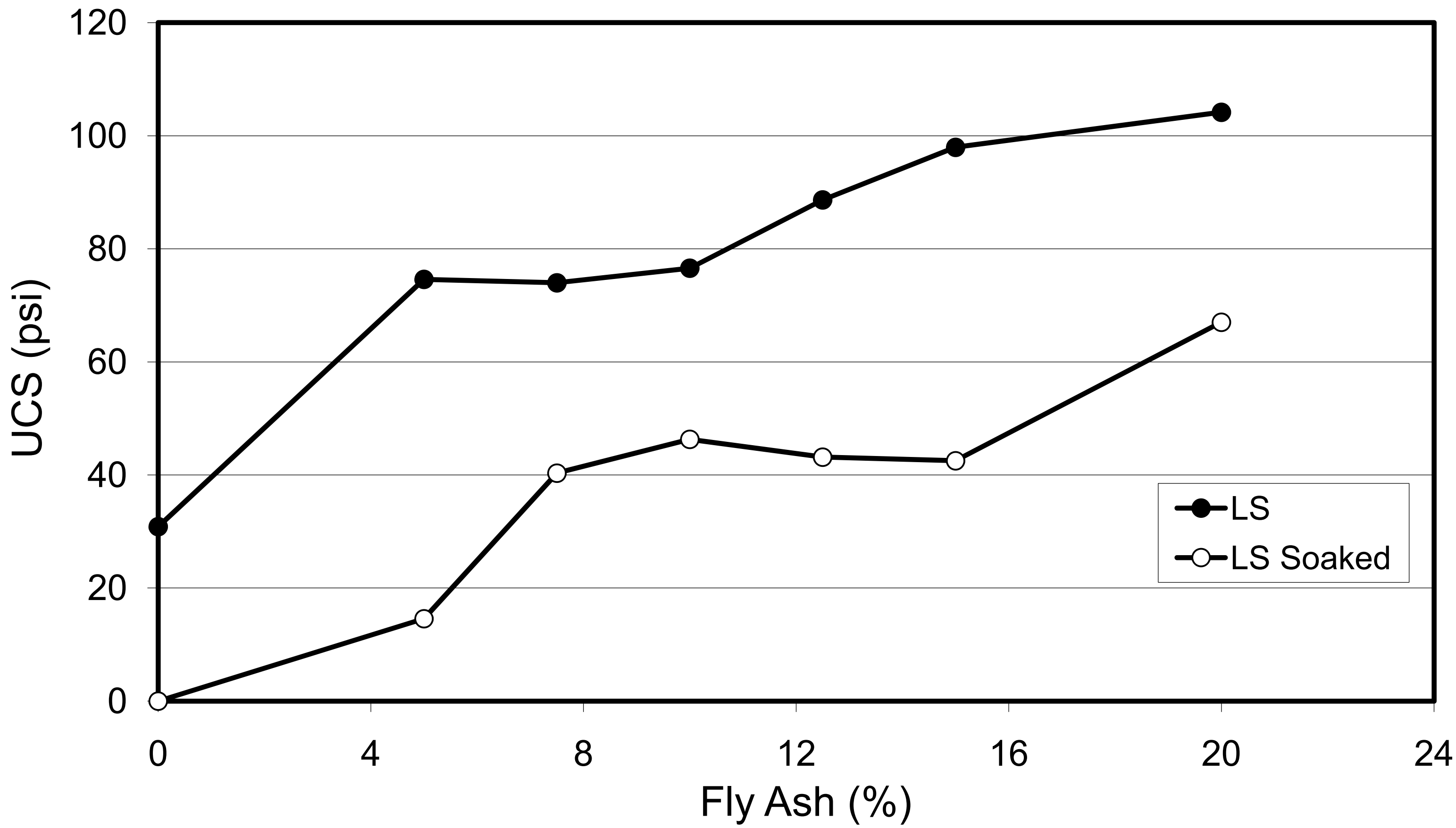


Figure 4.6a
Unconfined Compression Strength versus Curing Time
for Country Club Road, Payne County, Ok at 30% Fly Ash
(FS refers to a field mixed samples)

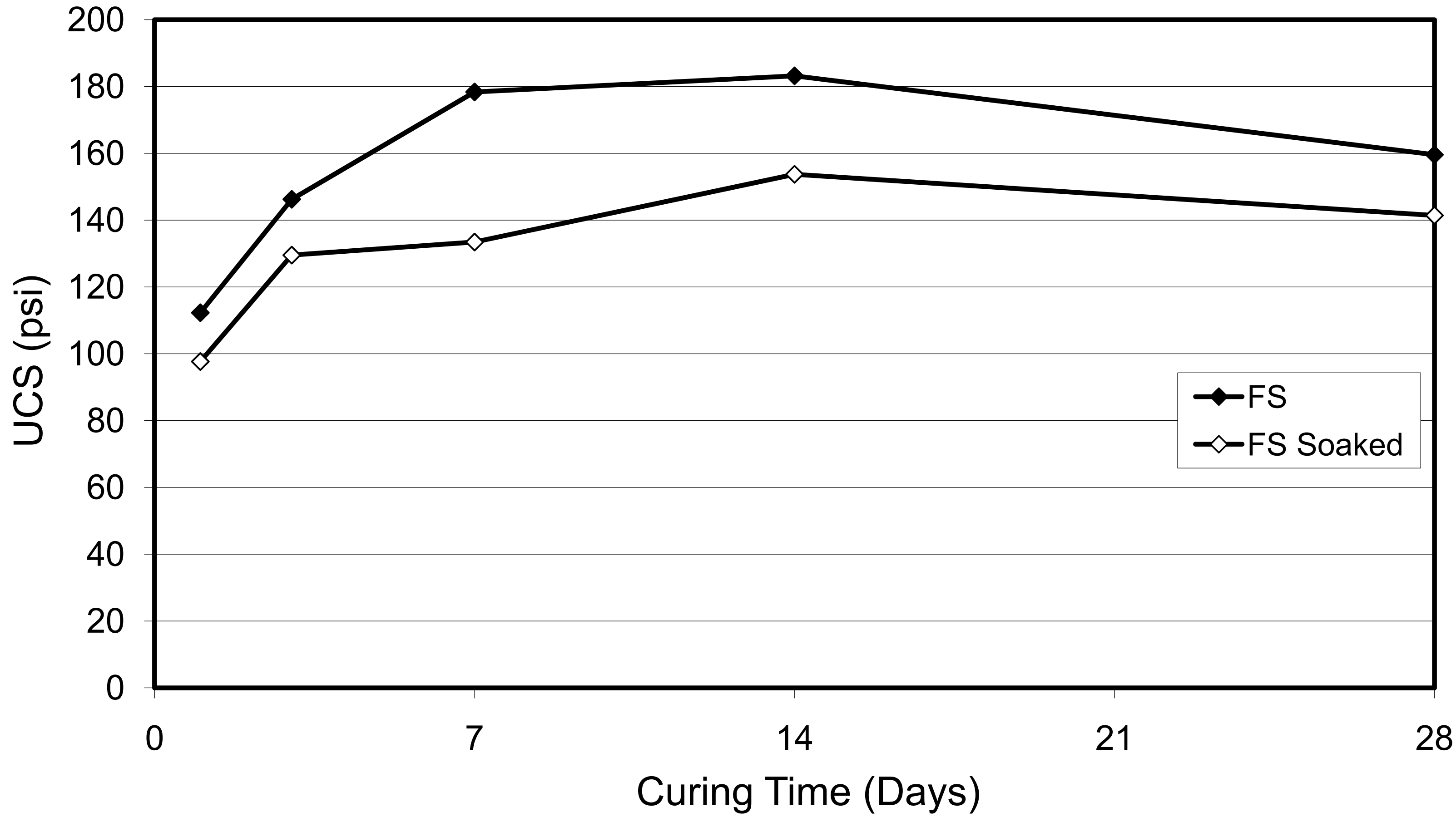


Figure 4.6b
Unconfined Compression Strength versus Curing Time
for Country Club Road, Payne County, Ok at 16% Fly Ash
(LS refers to a laboratory mixed samples)

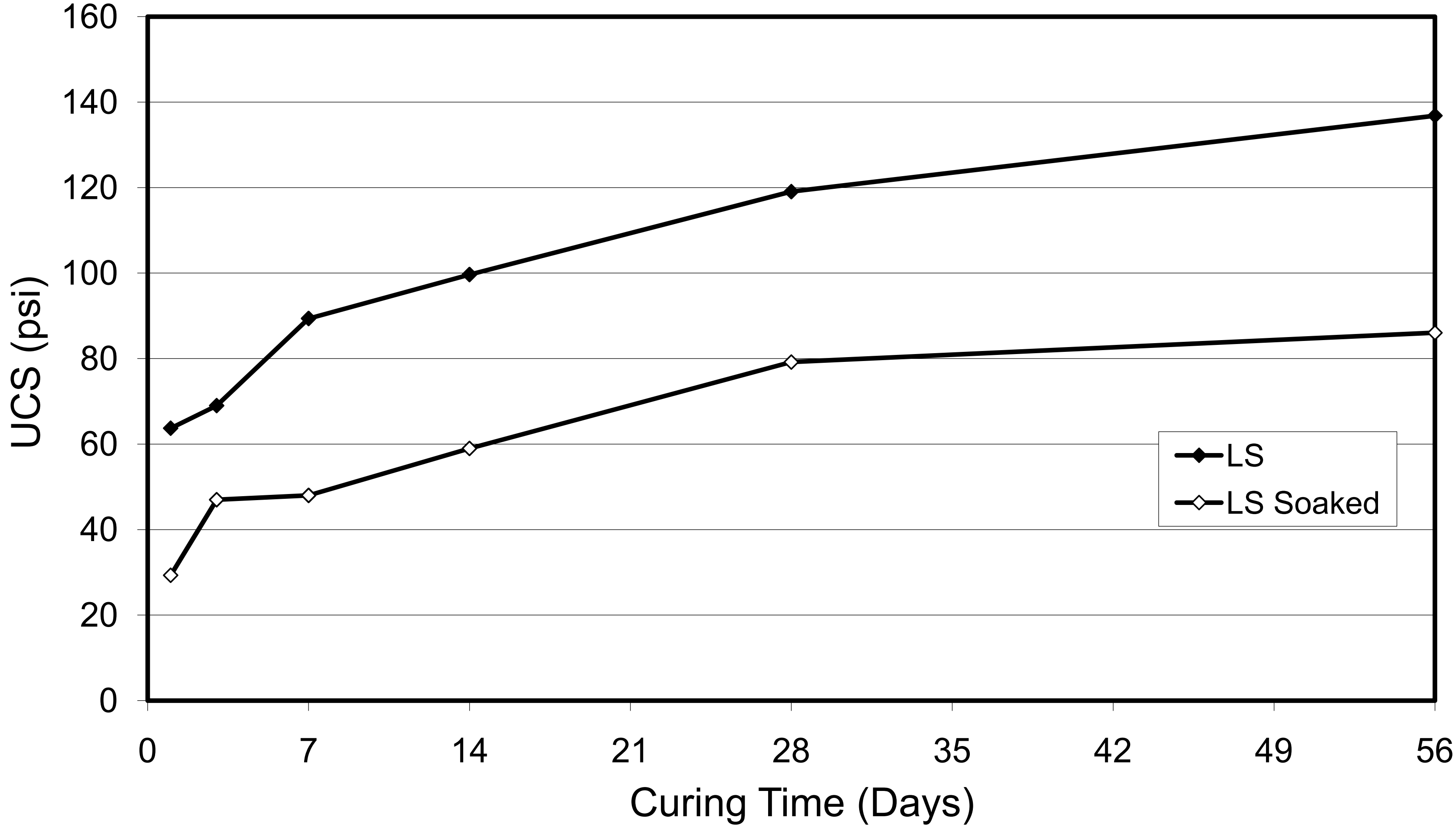
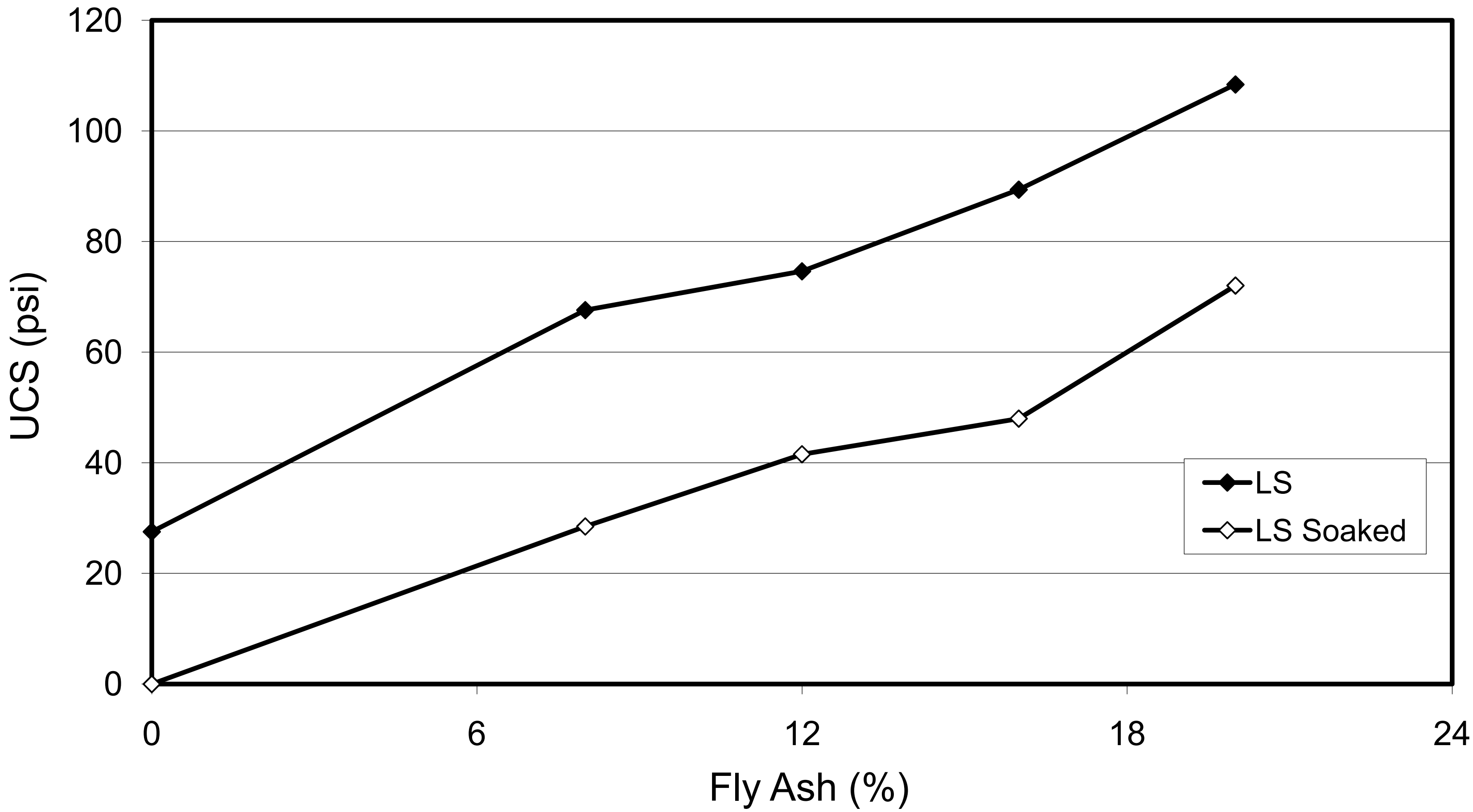


Figure 4.6c
Unconfined Compressive Strength versus Percent Additive
for Country Club Road, Payne County, Ok at a Curing Time of 7 Days
(LS refers to laboratory mixed samples)



Resilient Modulus

Figures 4.7a, 4.7b, and 4.7c show M_R with curing time for field mixed samples, M_R with curing time for laboratory mixed samples, and M_R with percent CKD for subgrade soils from Oakdale Dr. – North, Enid, respectively. For both field and laboratory mixed samples, M_R values increased rapidly through 14 day cure then leveled or dropped off. M_R values at 7 and 28 days were 99175 psi and 108837, respectively, for field mixed samples and 269011 psi and 345272 psi, respectively, for laboratory mixed samples. Laboratory mixed samples exhibited M_R values approximately three times the field mixed samples. Again this should be no surprise because of the difference in such items as sample preparation, additive mixing and sample preparation. M_R with % CKD increased rapidly through 10% CKD then dropped off at 14% CKD. Some of the variability of M_R values is likely due to the efficiency of the soil-CKD reaction for higher plasticity soils. It should be noted that the high M_R values obviously indicate a stiff material under dynamic load; however, an associated problem with M_R testing of very stiff material is consistent measurement of small amounts of resilient strain. Small variations in strain can cause significant differences in measured M_R values when the apparent stiffness is not dramatically different. In other words, changes in M_R values between 300000 psi and 600000 psi may not actually reflect that large of a difference in stiffness of the material, rather an indication of potential problems inherent in the test method.

Figure 4.7a
Resilient Modulus (M_R) versus Curing Time for Field Mixed Samples
Oakdale Dr. - North, Enid, Ok

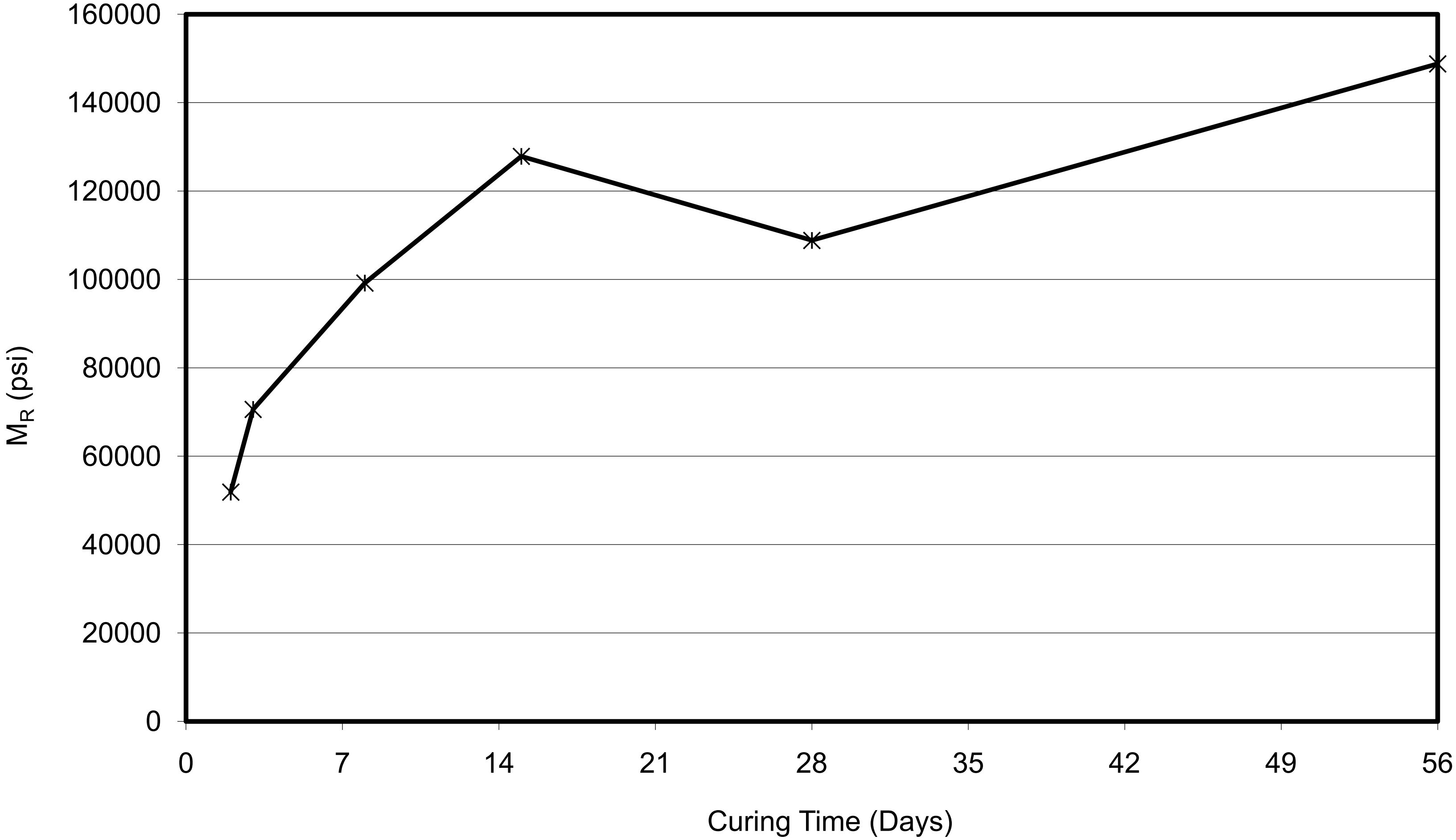


Figure 4.7b
Resilient Modulus (M_R) versus Curing Time for Laboratory Mixed Samples
Oakdale Dr. - North, Enid, Ok

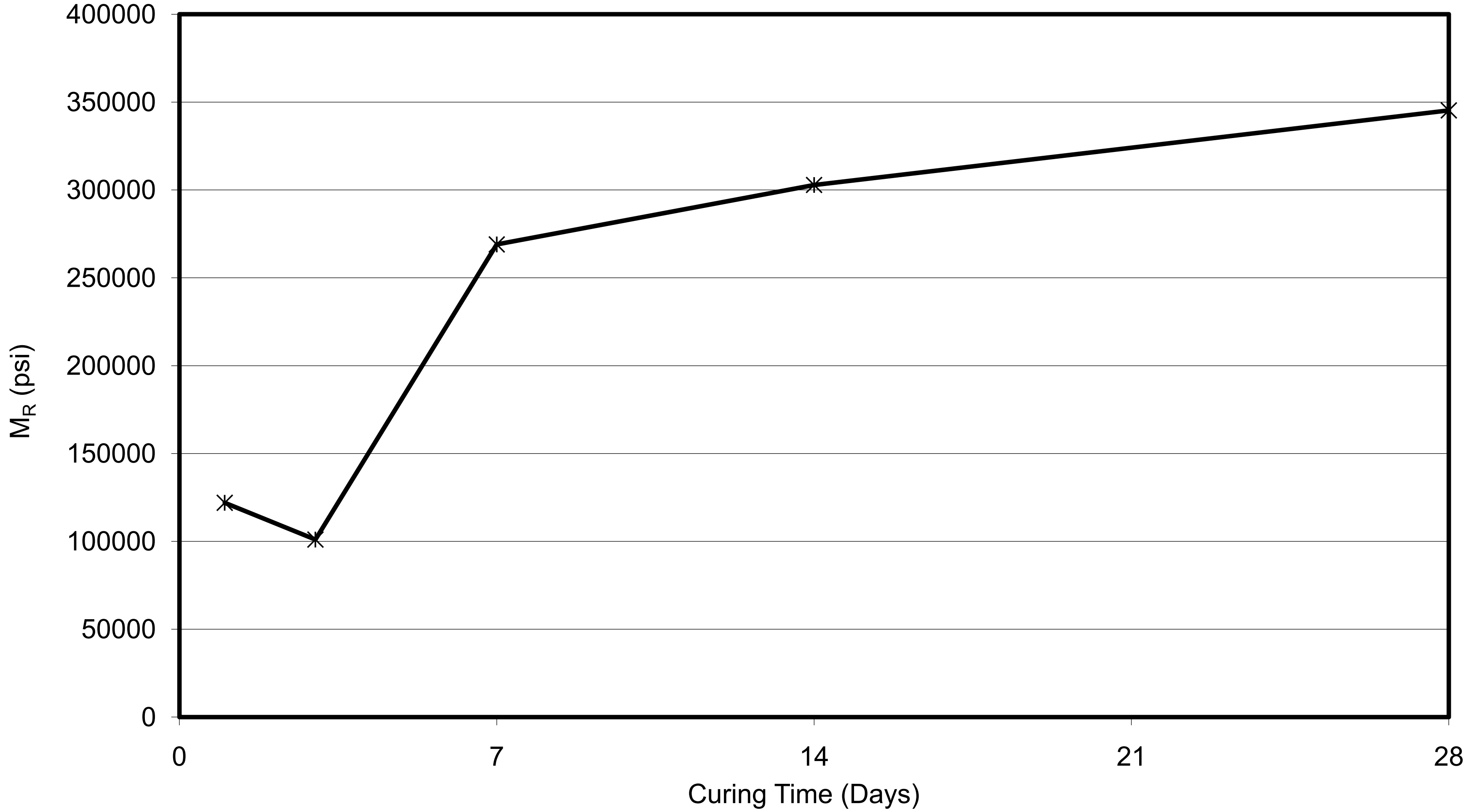


Figure 4.7c
Resilient Modulus (M_R) versus CKD Percentage (7 - day cure)
Laboratory Mixed Samples for Oakdale Dr. - North, Enid, Ok

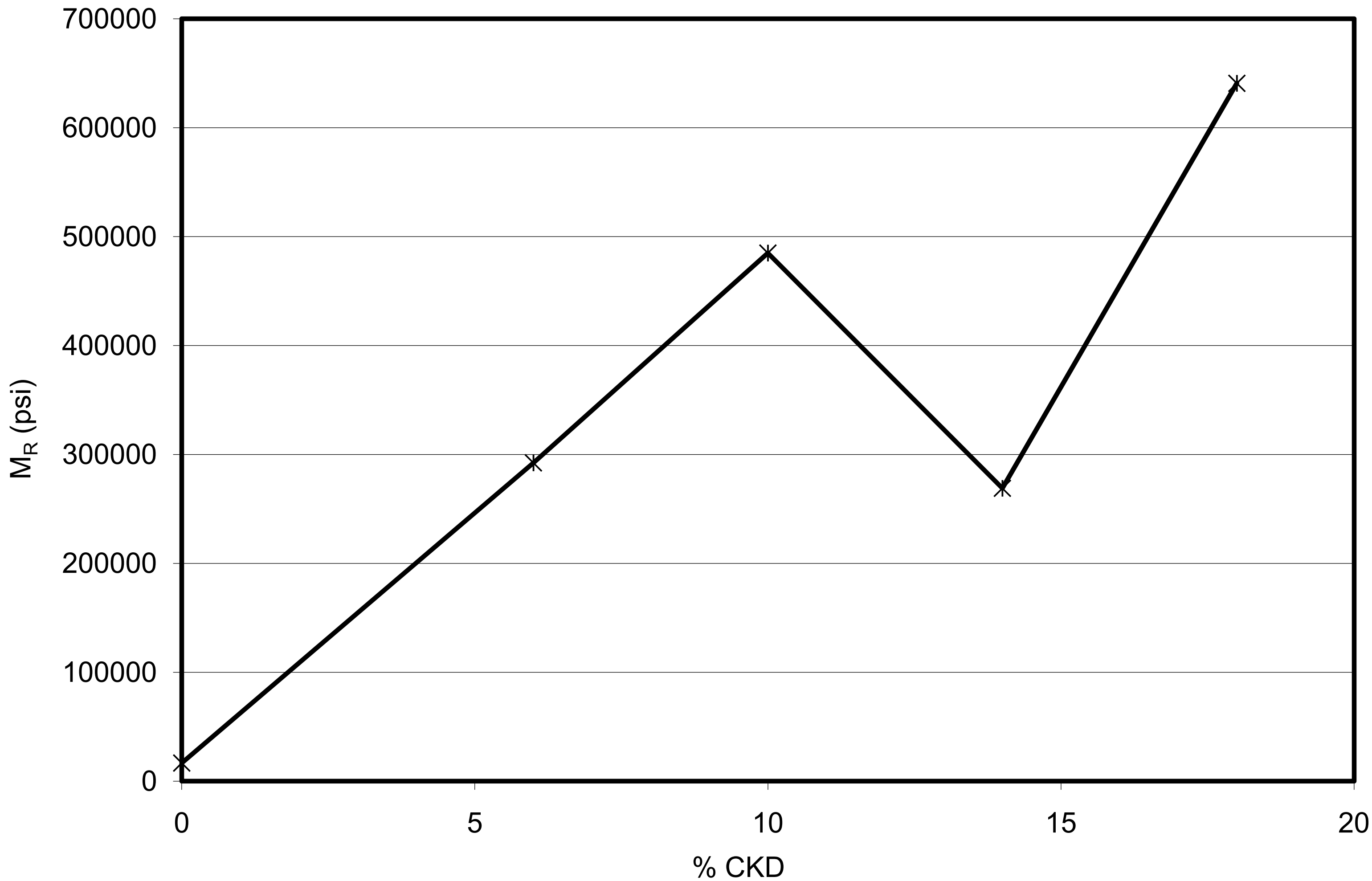


Figure 4.8a, 4.8b, and 4.8c show M_R with curing time for field mixed samples, M_R with curing time for laboratory mixed samples, and M_R with percent CKD for subgrade soils from Oakdale Dr – South, Enid, respectively. M_R values for field mixed samples increased rapidly through 14 day cure, then increased at a lower rate through 56 day cure. M_R values for laboratory mixed samples increased rapidly through 14 day cure with only a small change in rate of strength going through 28 days. M_R values at 7 and 28 days were 54088 psi and 81156 psi, respectively, for field mixed samples and 141576 psi and 610410 psi, respectively, for laboratory mixed samples. The differences between field and laboratory mixed samples were greater for this site probably because of the lower plasticity, more granular nature of the soils (e.g. easy to mix with the CKD and less influence of the soil activity on use of cementitious products in CKD). M_R with % CKD showed significant increases through the range of percentages tested with no indication of leveling or dropping off at higher percentages.

Figure 4.9a, 4.9b, and 4.9c show M_R with curing time for field mixed samples, M_R with curing time for laboratory mixed samples, and M_R with percent fly ash for subgrade soils from U.S. 62, Anadarko, respectively. M_R values for both field and laboratory mixed samples exhibit similar trends, with rapid increases in M_R throughout 14 day cure, then essentially leveling off through 56 day cure. M_R values at 7 and 28 days were 42062 psi and 75431 psi, respectively, for field mixed samples and 67213 psi and 84127 psi, respectively, for laboratory mixed samples. M_R values for laboratory mixed samples showed only modest increases over field mixed samples at the respective curing times. Considering that the soils at Oakdale Dr. – South and Anadarko are similar, the smaller increases in M_R are likely the result of the differences between class C fly ash and CKD. M_R with % fly ash showed significant increase through the range of percentages tested, with no indication of leveling or dropping off at higher percentages.

Figure 4.8a
Resilient Modulus (M_R) versus Curing Time for Field Mixed Samples
Oakdale Dr. - South, Enid, Ok

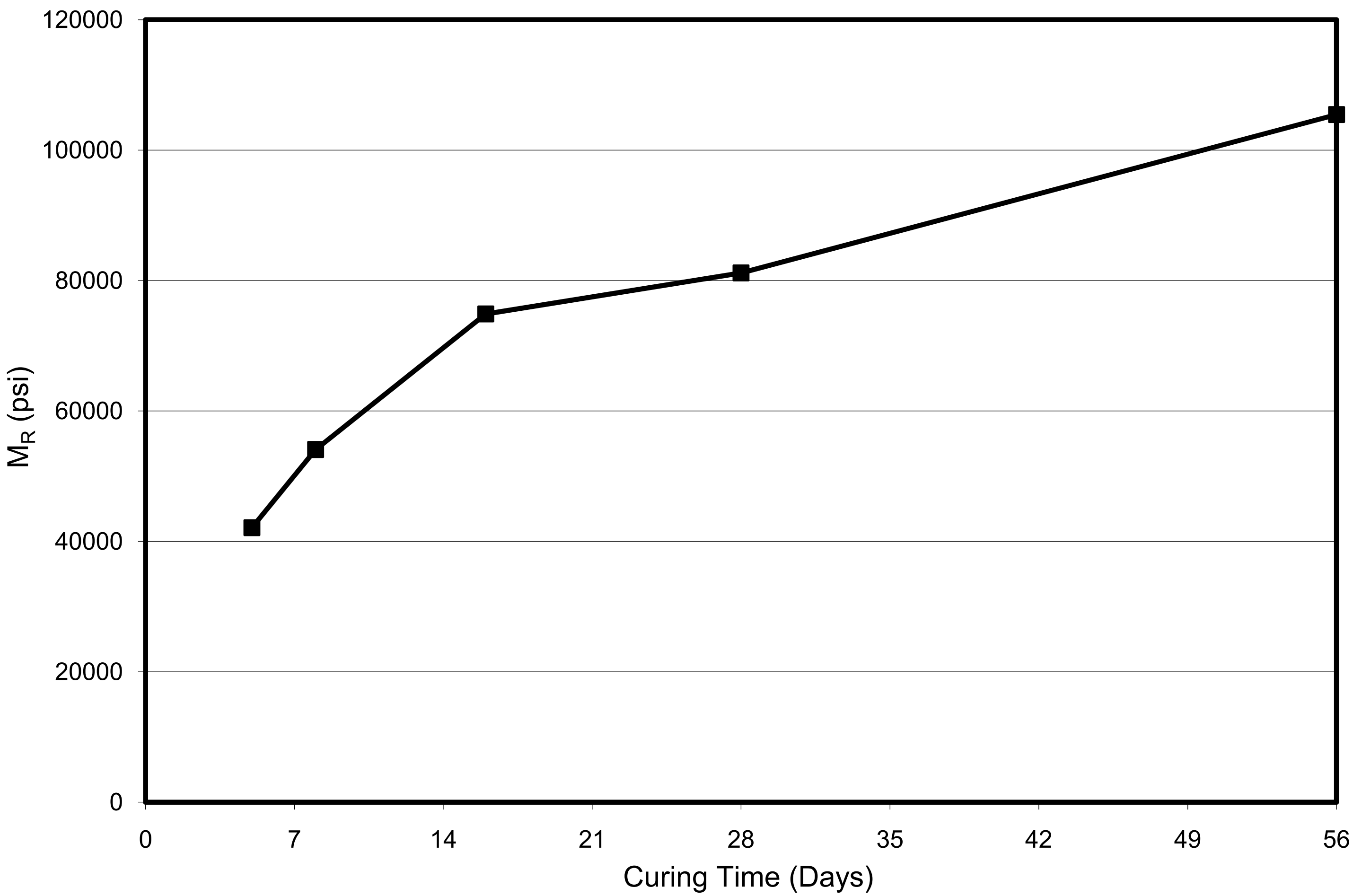


Figure 4.8b
Resilient Modulus (M_R) versus Curing Time for Laboratory Mixed Samples
Oakdale Dr. - South, Enid, Ok

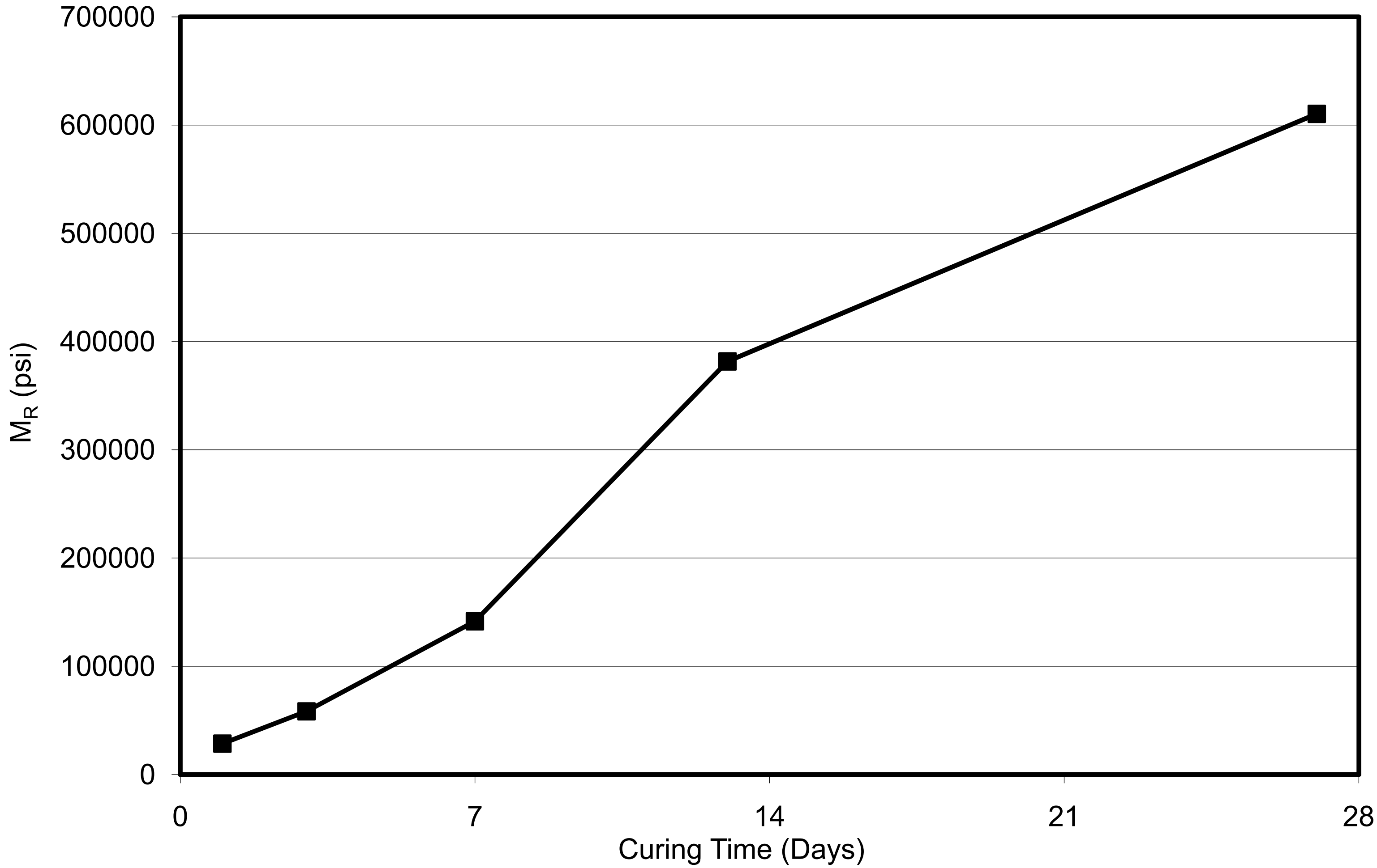


Figure 4.8c
Resilient Modulus (M_R) versus CKD Percentage (7 - day cure)
Laboratory Mixed Samples for Oakdale Dr. - South, Enid, Ok

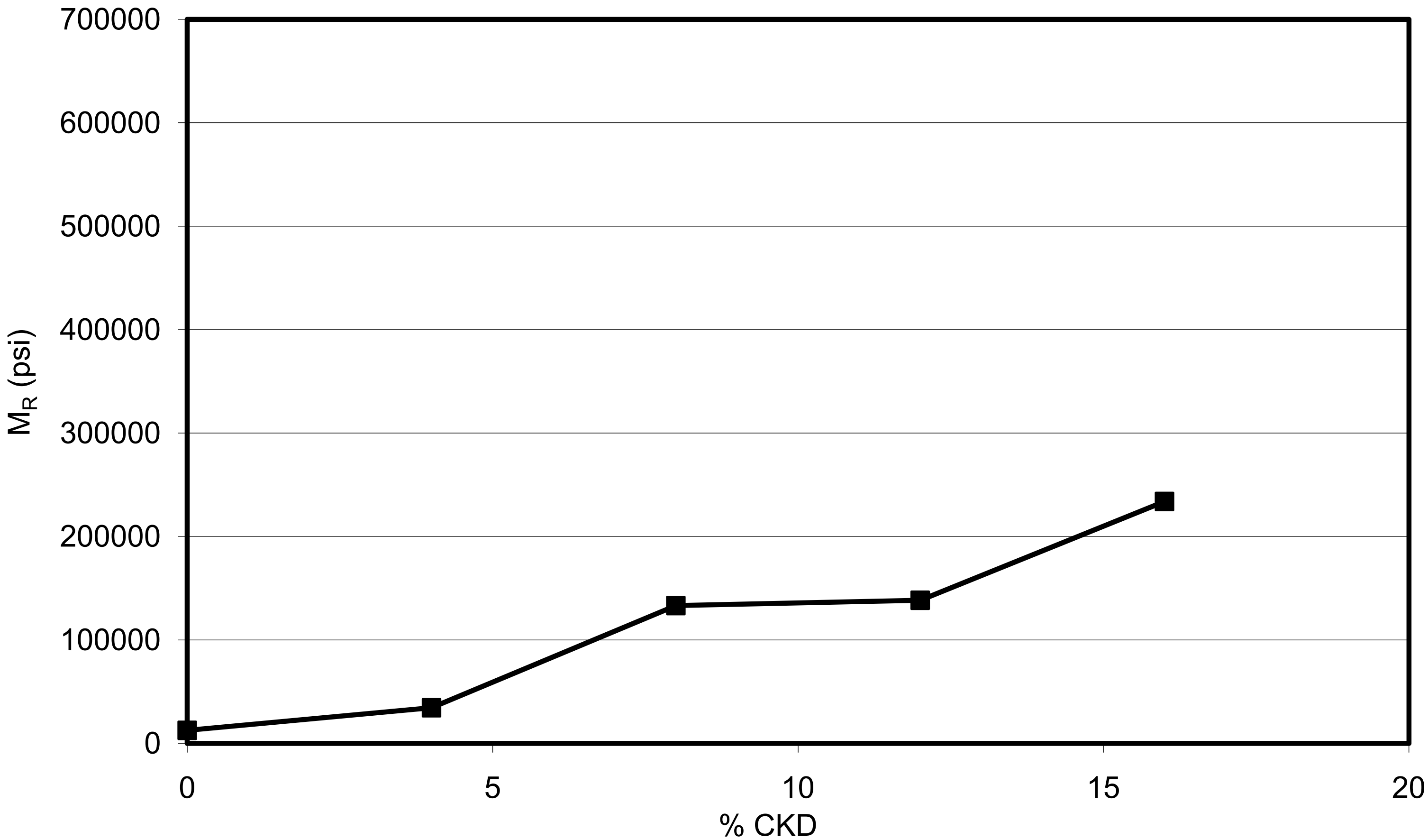


Figure 4.9a
Resilient Modulus (M_R) versus Curing Time for Field Mixed Samples
U.S. 62, Anadarko, Ok

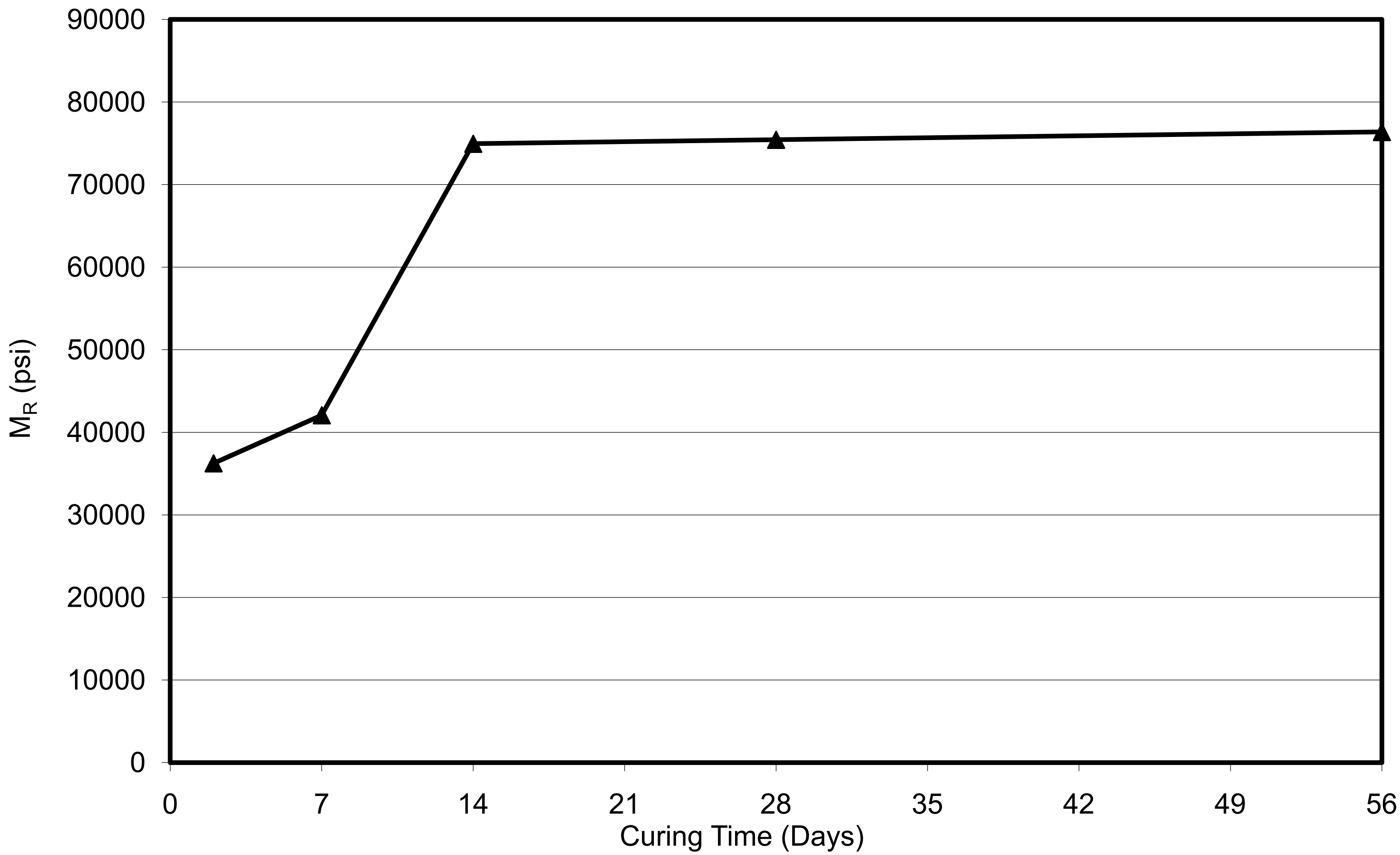


Figure 4.9b
Resilient Modulus (M_R) versus Curing Time for Laboratory Mixed Samples
U.S. 62, Anadarko, Ok

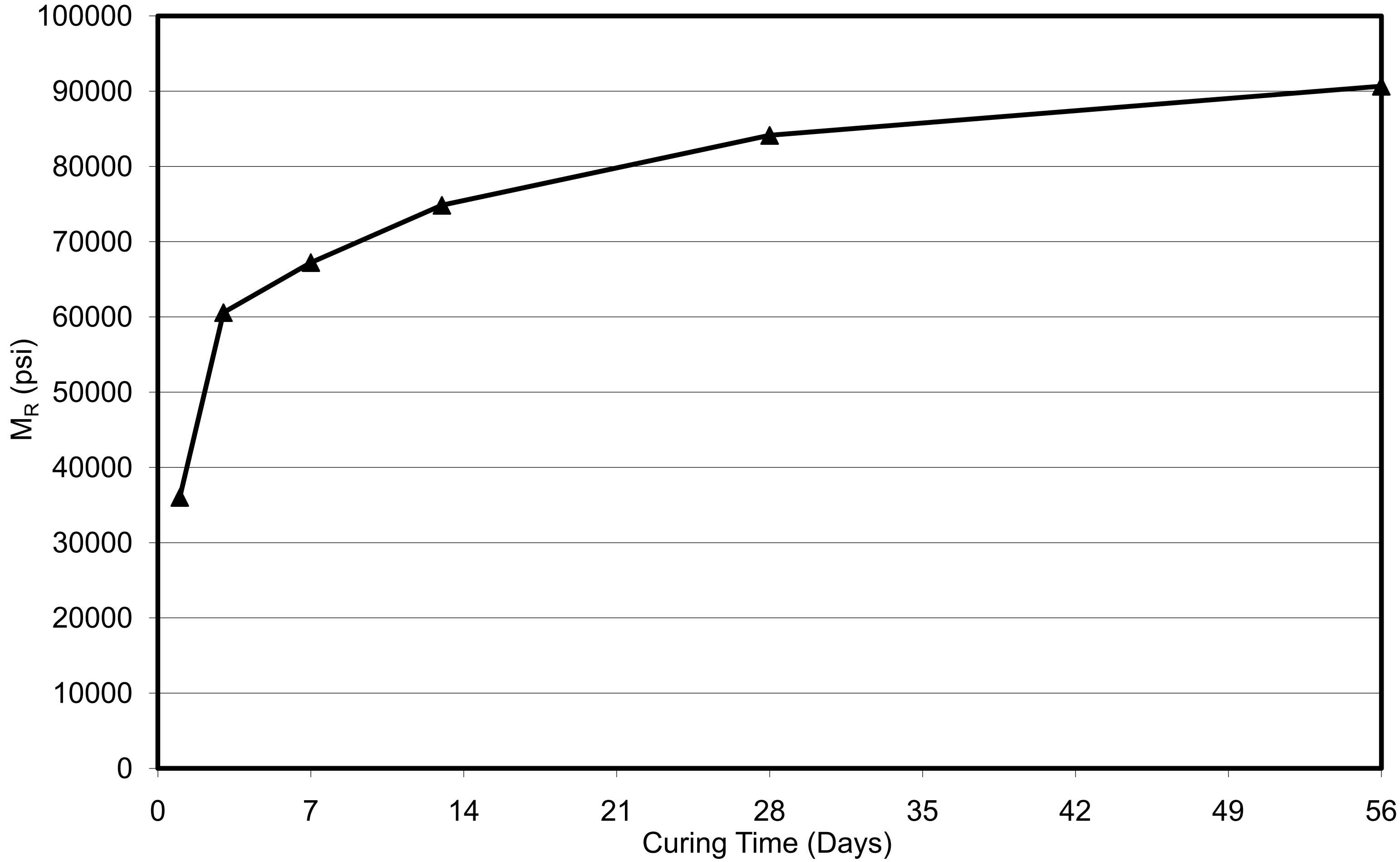
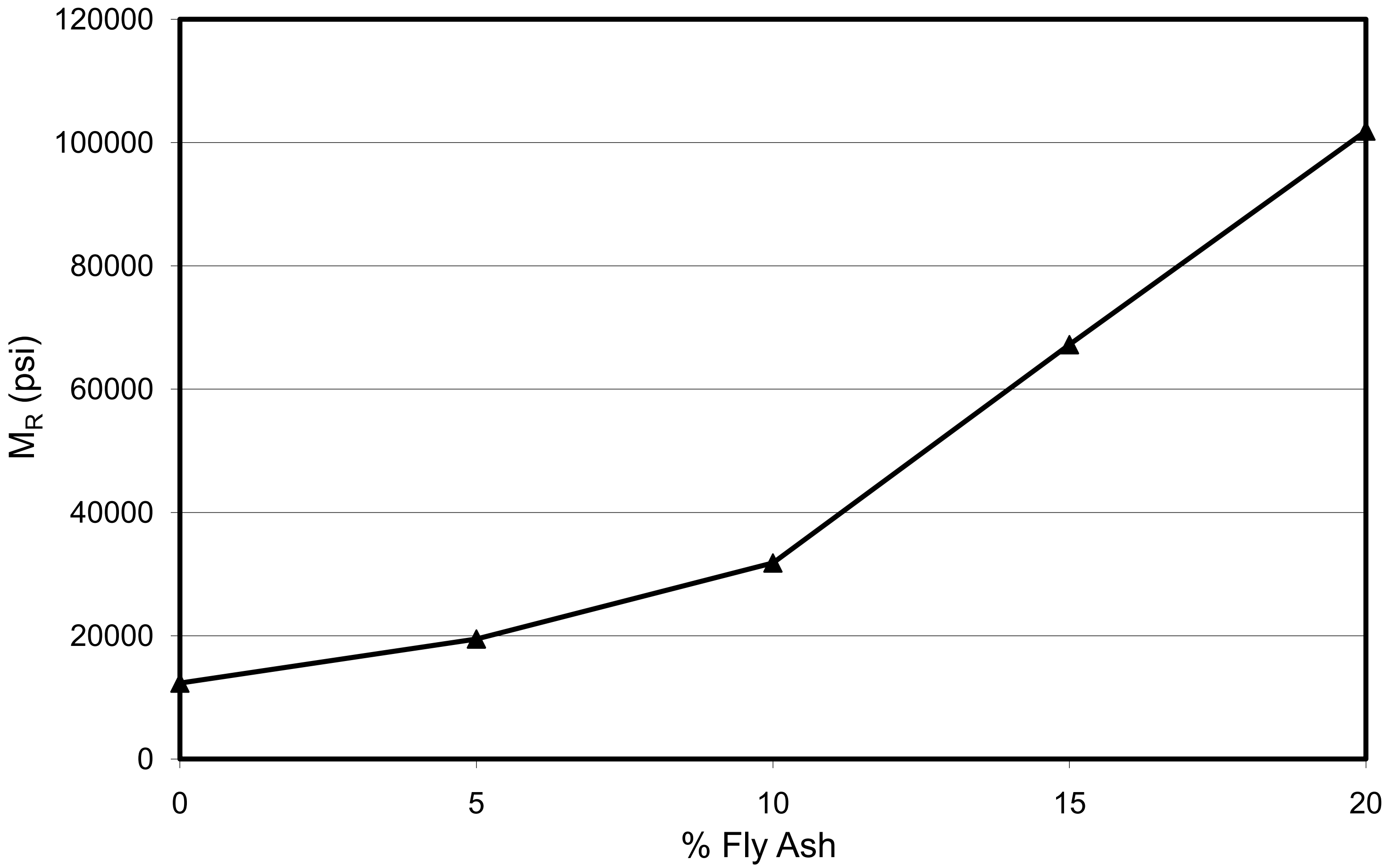


Figure 4.9c
Resilient Modulus (M_R) versus Fly Ash Percentage (7 - day cure)
Laboratory Mixed Samples for U.S. 62, Anadarko, Ok



Figures 4.10a, 4.10b, and 4.10c show M_R with curing time for field mixed samples, M_R with curing time for laboratory mixed samples, and M_R with percent fly ash for subgrade soils from 15th Street, Perry, respectively. M_R values for field mixed samples increased to a maximum at 28 day cure then dropped off. M_R values for laboratory mixed samples increased rapidly through 7 day cure then dropped off slightly and leveled off. M_R values at 7 and 28 days were 25566 psi and 40046 psi, respectively, for field mixed samples and 113563 psi and 133579 psi, respectively, for laboratory mixed samples. The significant difference in M_R values between field and laboratory mixed samples are likely the result of difference in mixing between field and laboratory (e.g. more difficult to achieve efficient mixing when treating high plasticity materials). Actually, the soils at the Perry site would have qualified for pretreatment (e.g. PI > 20) which would have made mixing less difficult. M_R with % fly ash showed a significant increase through 10%, then M_R dropped off at 15% showing the typical peak values.

Figures 4.11a, 4.11b, and 4.11c show M_R with curing time for field mixed samples, M_R curing time for laboratory mixed samples, and M_R with percent fly ash for subgrade soils from Country Club Road, Payne County, respectively. M_R values for field mixed samples showed a rapid increase through 14 day cure then dropped and leveled off. M_R values for laboratory mixed samples showed a more modest increase between 3 and 56 day cure. The unusually high M_R value at 1 day cure could not be explained from a test procedure or sample condition point of view. M_R values at 7 and 28 days were 141765 psi and 144929 psi, respectively, for field mixed samples and 44531 psi and 64193 psi, respectively, for laboratory mixed samples. The difference in M_R values, higher for field mixed samples as compared to laboratory mixed samples, was due to the difference in % fly ash used (see discussion of UCS results). M_R with % fly ash showed a rather erratic behavior which was likely related to the M_R test procedure.

Figure 4.10a
Resilient Modulus (M_R) versus Curing Time for Field Mixed Samples
15th Street, Perry, Ok

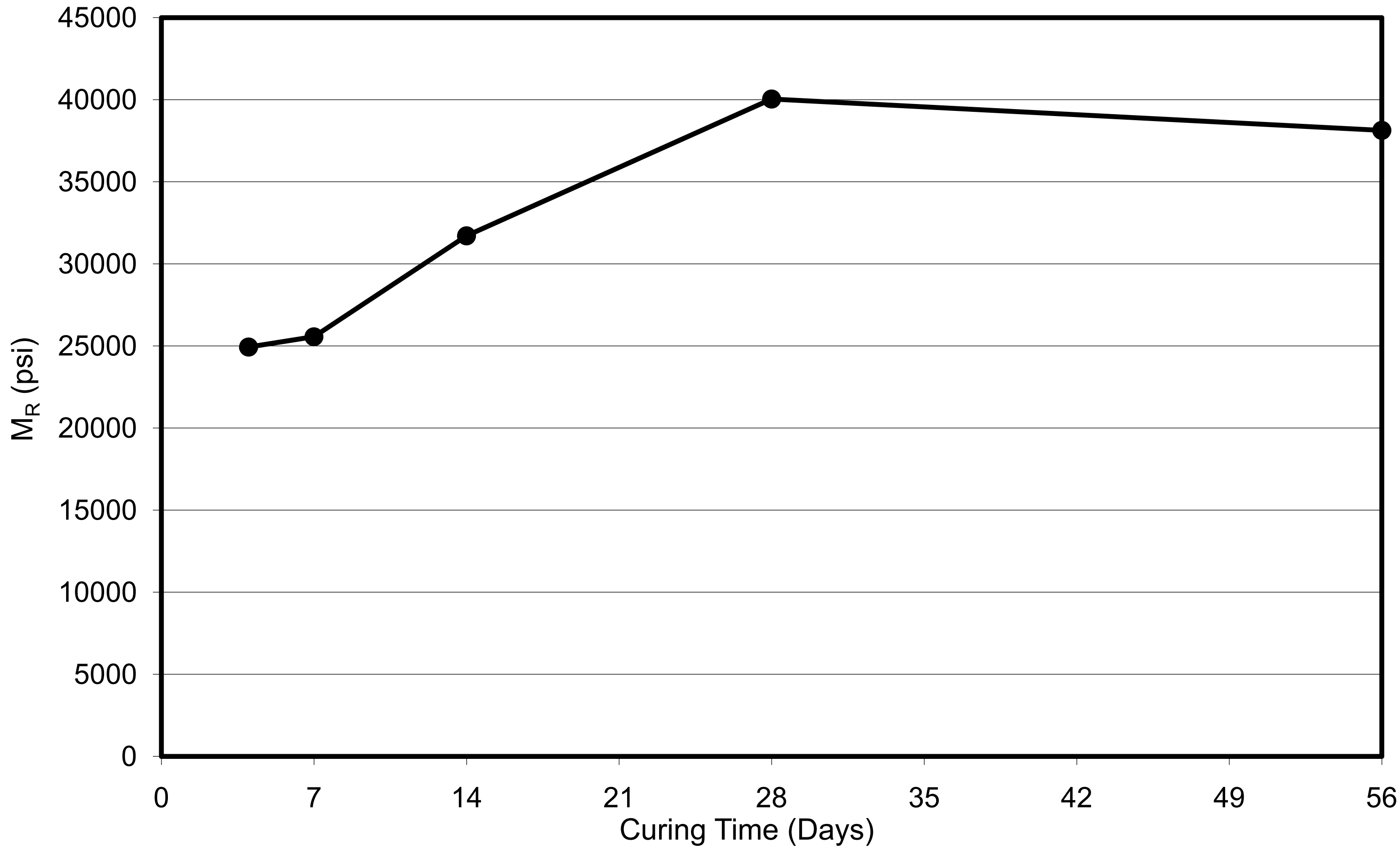


Figure 4.10b
Resilient Modulus (M_R) versus Curing Time for Laboratory Mixed Samples
15th Street, Perry, Ok

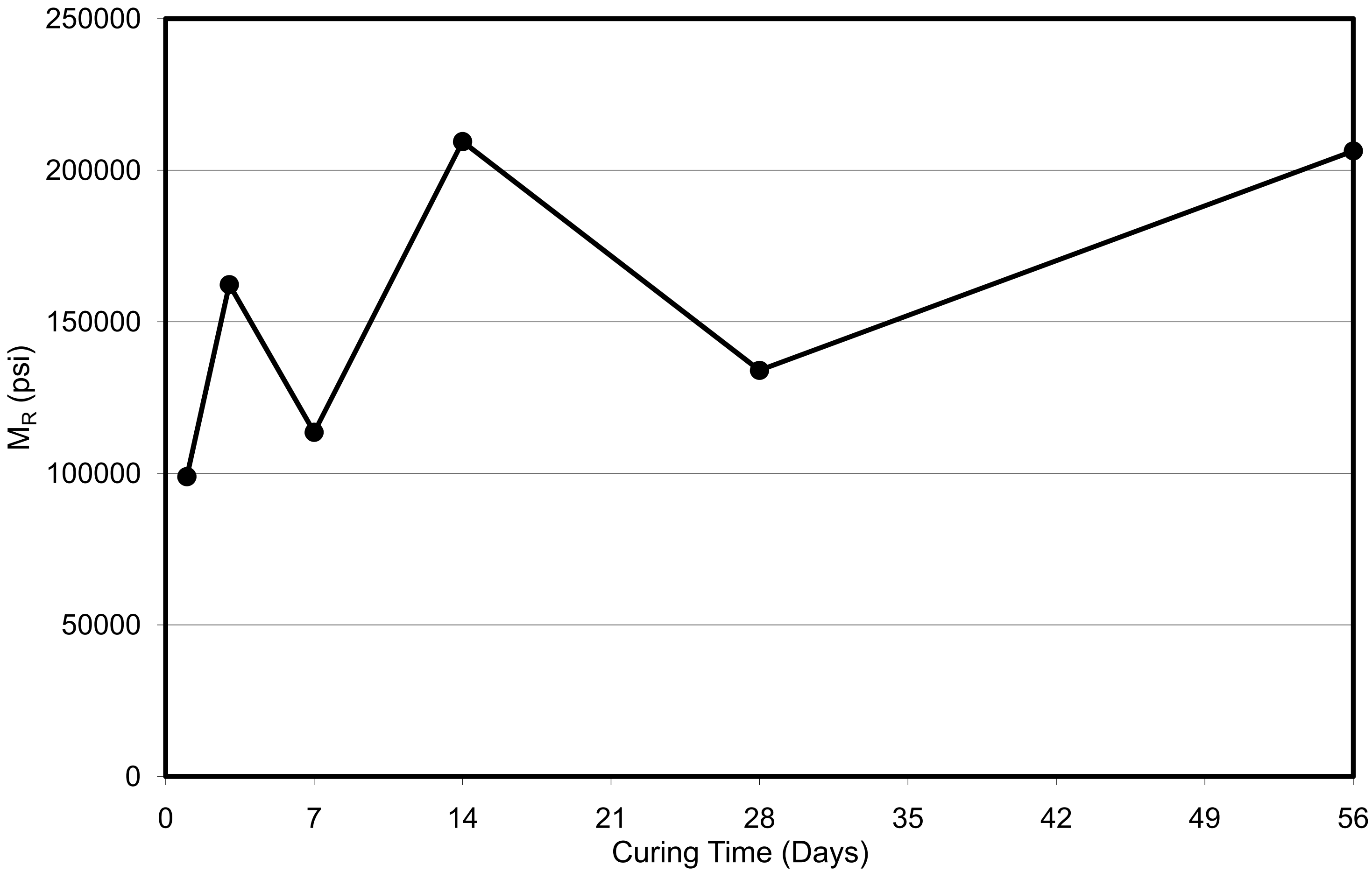


Figure 4.10c
Resilient Modulus (M_R) versus CKD Percentage (7 - day cure)
Laboratory Mixed Samples for 15th Street, Perry, Ok

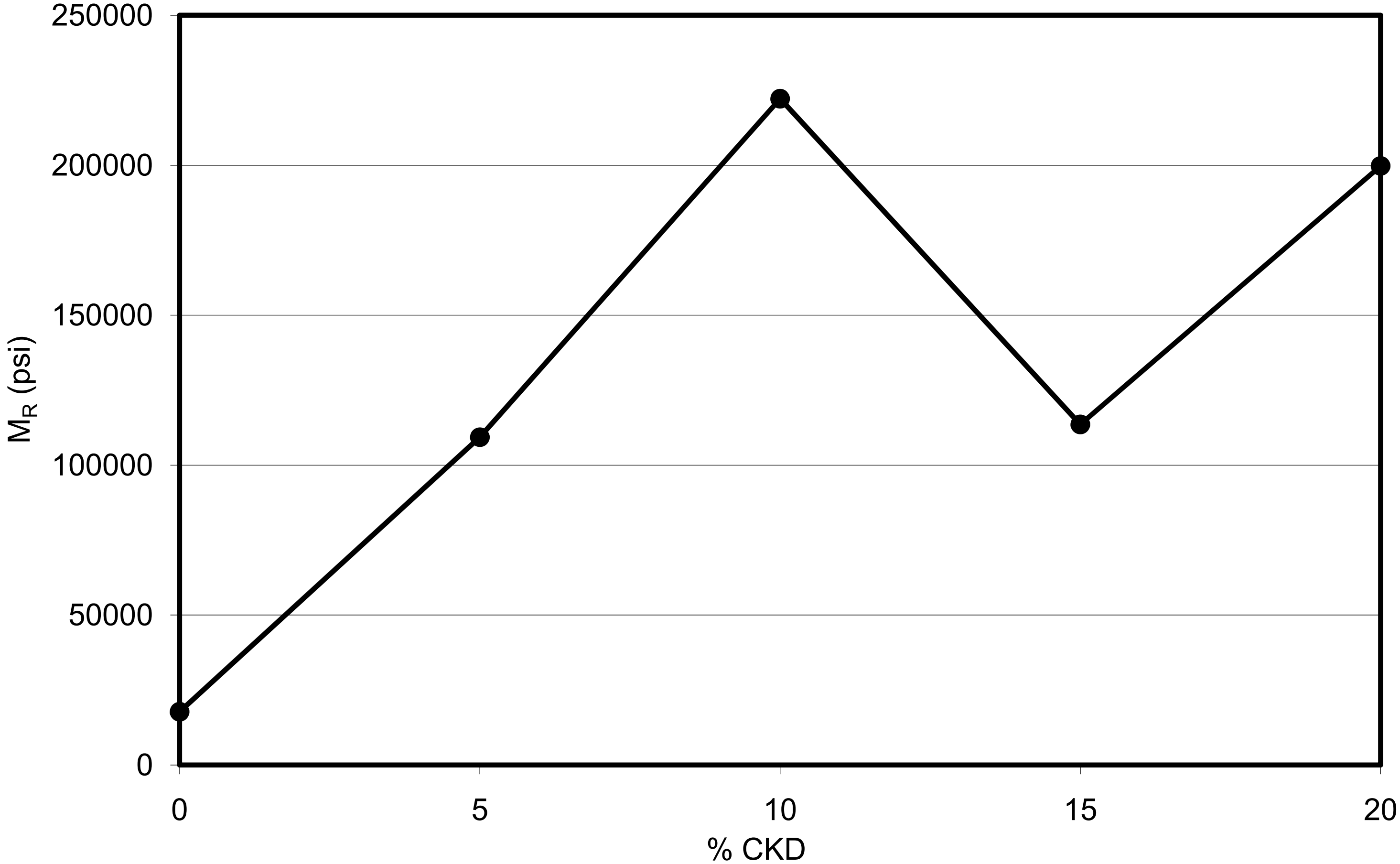


Figure 4.11a
Resilient Modulus (M_R) versus Curing Time for Field Mixed Samples
Country Club Road, Payne County, Ok

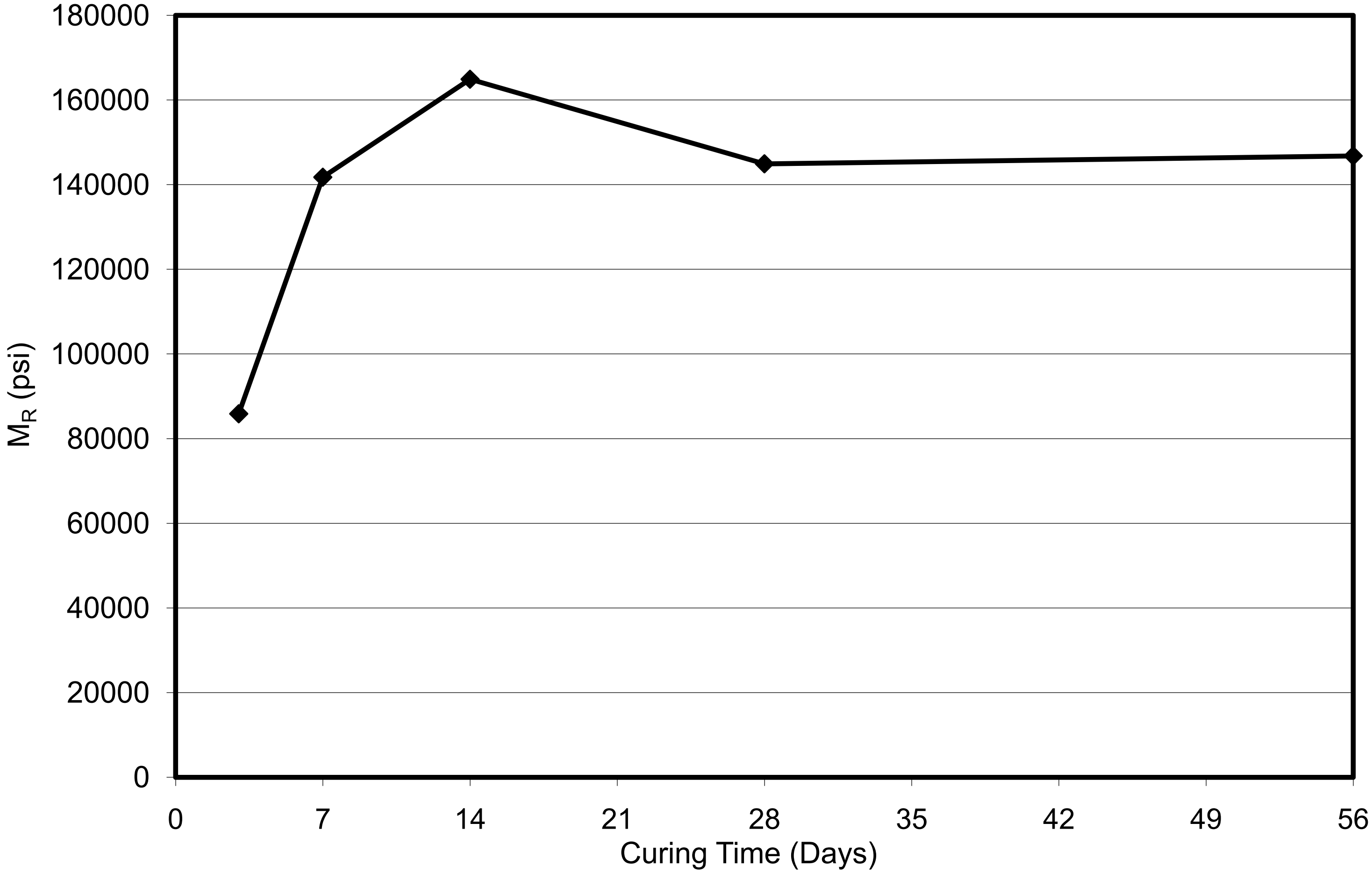


Figure 4.11b
Resilient Modulus (M_R) versus Curing Time for Laboratory Mixed Samples
Country Club Road, Payne County, Ok

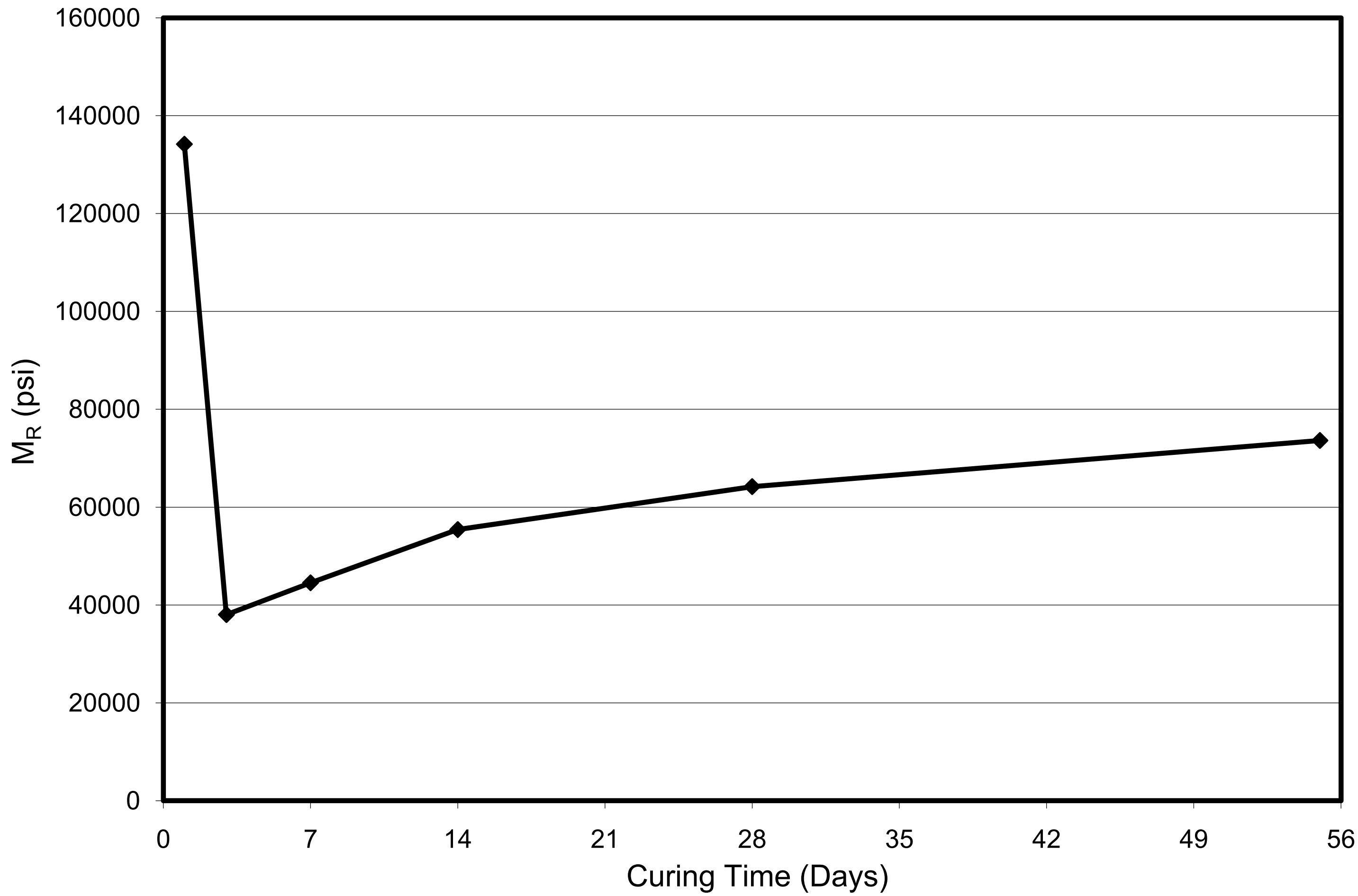
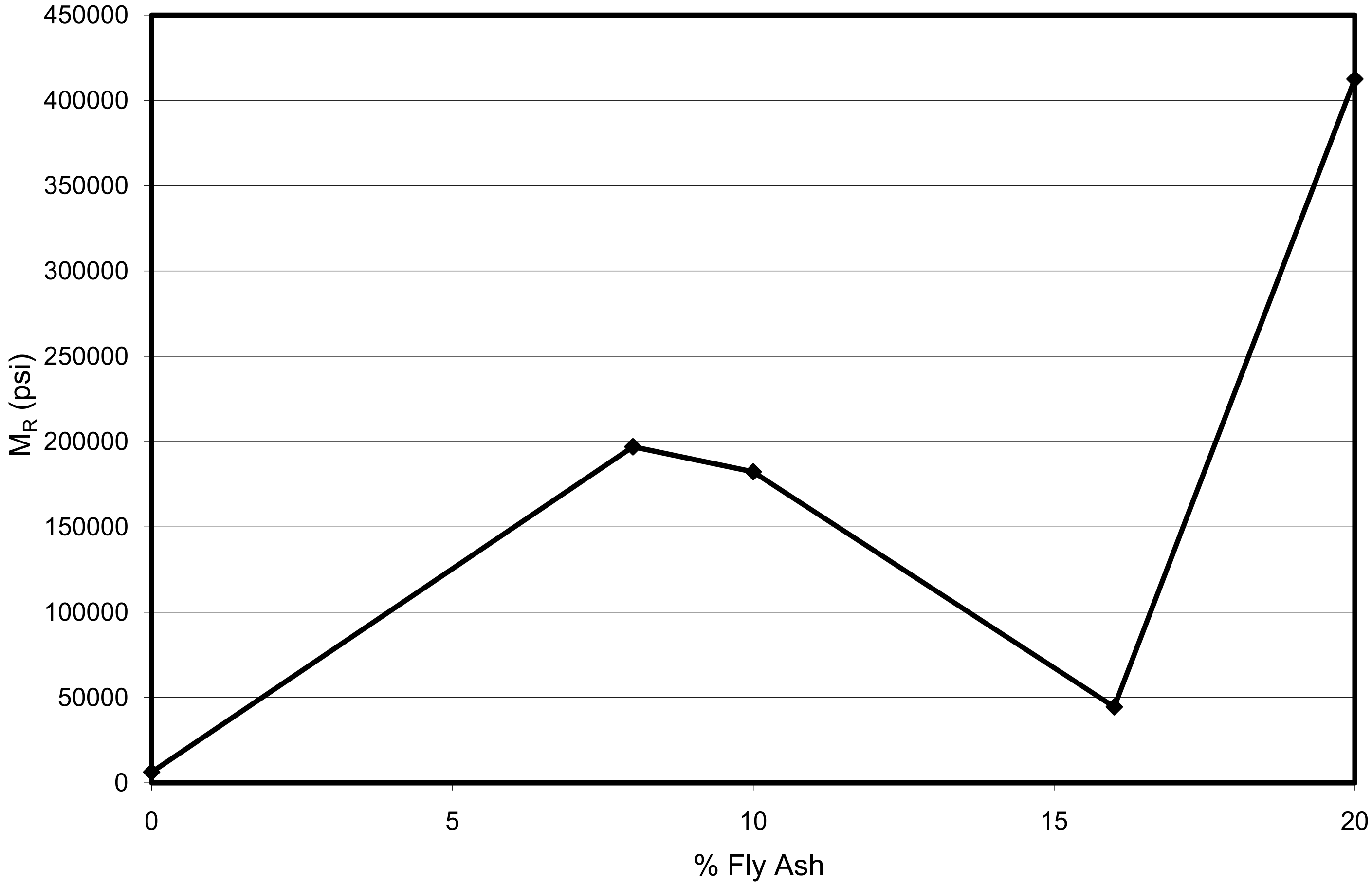


Figure 4.11c
Resilient Modulus (M_R) versus Fly Ash Percentage (7 - day cure)
Laboratory Mixed Samples for Country Club Road, Payne County, Ok



Field Data

Field data was collected on schedules controlled by access to the untreated/treated subgrade based on project construction (e.g. paving) schedule. All five field test sites were monitored for untreated conditions and at least two curing times following treatment, with three or four monitoring visits typically made. All field data is summarized in Tables 7 and 8 of each appendix. Presentation and discussion of the field data will be based on instrument used.

Moisture Content and Dry Density

Figures 4.12a, b, c, d, and e show moisture content and dry density data collected using a Troxler Model 3440 Nuclear w-γ gauge. The trends are a bit erratic but generally consistent with dry density and moisture content generally decreasing and leveling off with time. The "0" curing time represents untreated subgrade soil conditions with the time between monitoring of untreated conditions and stabilization varying due to access availability and construction schedule. Once the project was paved, no further monitoring was conducted.

Stiffness

Figures 4.13a, b, c, d, and e show stiffness (K in MN/m) data collected using a Humbolt Stiffness Gauge. The modulus (E in MN/m^2) data was calculated from stiffness values using an appropriate Poisson's Ratio (see AASHTO MEPDG). With one exception, stiffness and modulus generally increased with curing time, as would be expected; however, the increase in stiffness and modulus do not occur as rapidly as UCS on M_R from laboratory testing.

Figure 4.12a
Nuclear w - γ Gauge Readings
(Moisture Content and Dry Density)
for Oakdale Dr. - North, Enid, Ok

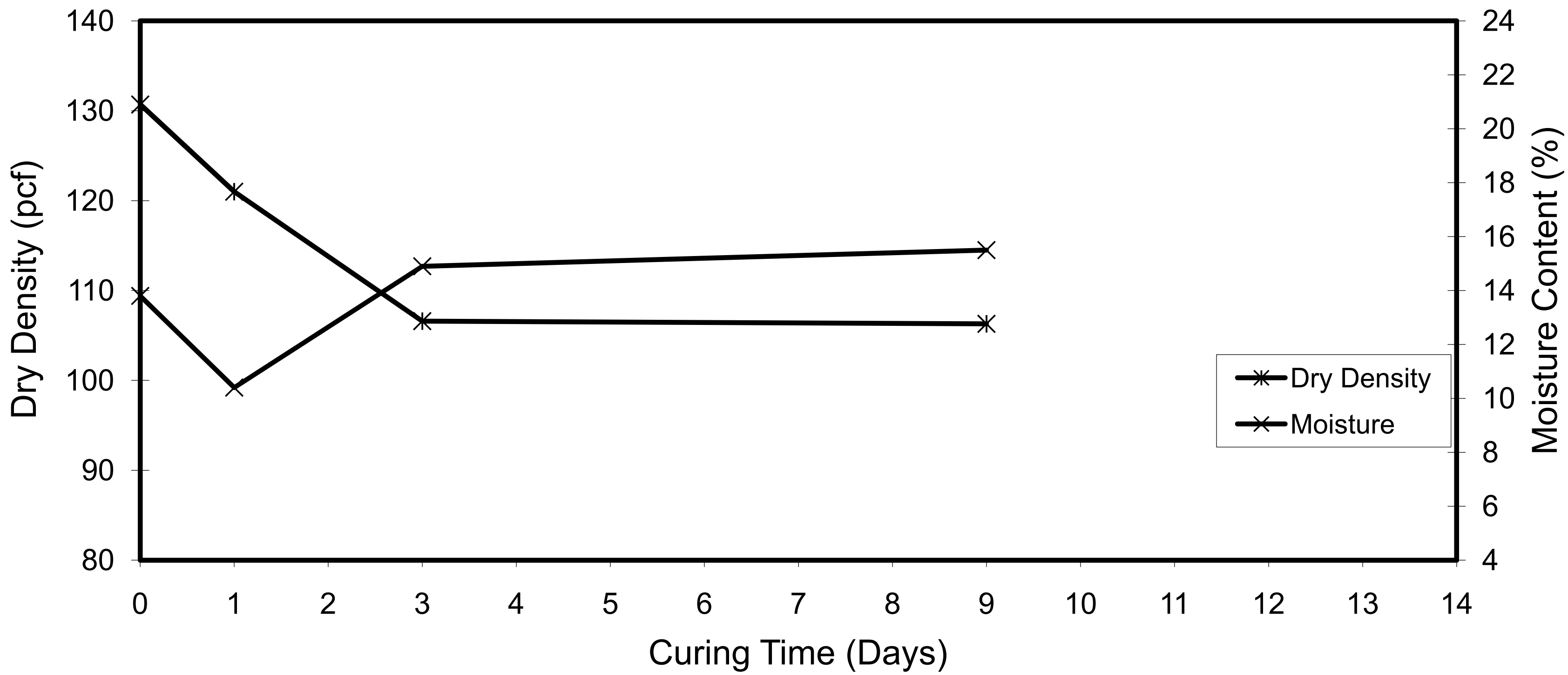


Figure 4.12b
Nuclear w - γ Gauge Readings
(Moisture Content and Dry Density)
for Oakdale Dr. - South, Enid, Ok

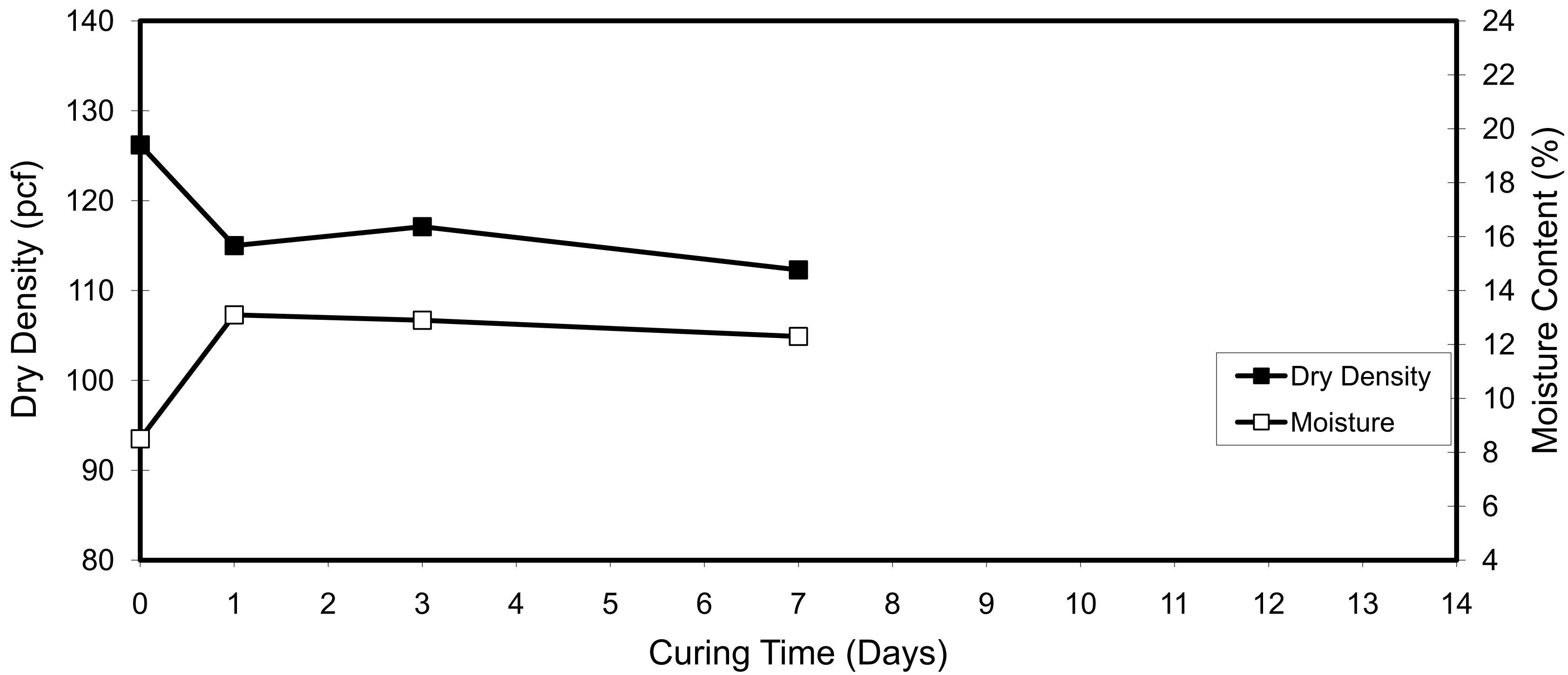


Figure 4.12c
Nuclear w - γ Gauge Readings
(Moisture Content and Dry Density)
for U.S. 62, Anadarko, Ok

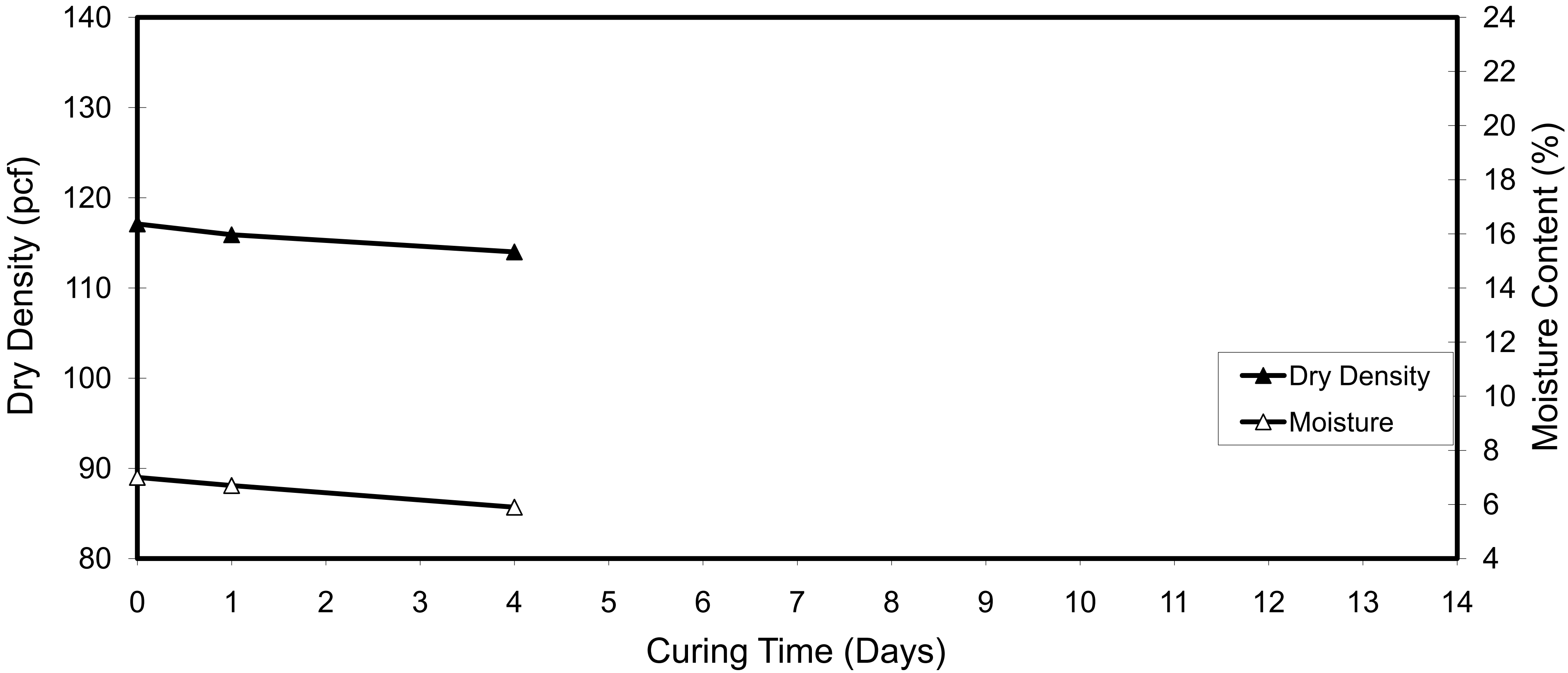


Figure 4.12d
Nuclear w - γ Gauge Readings
(Moisture Content and Dry Density)
for 15th Street, Perry, Ok

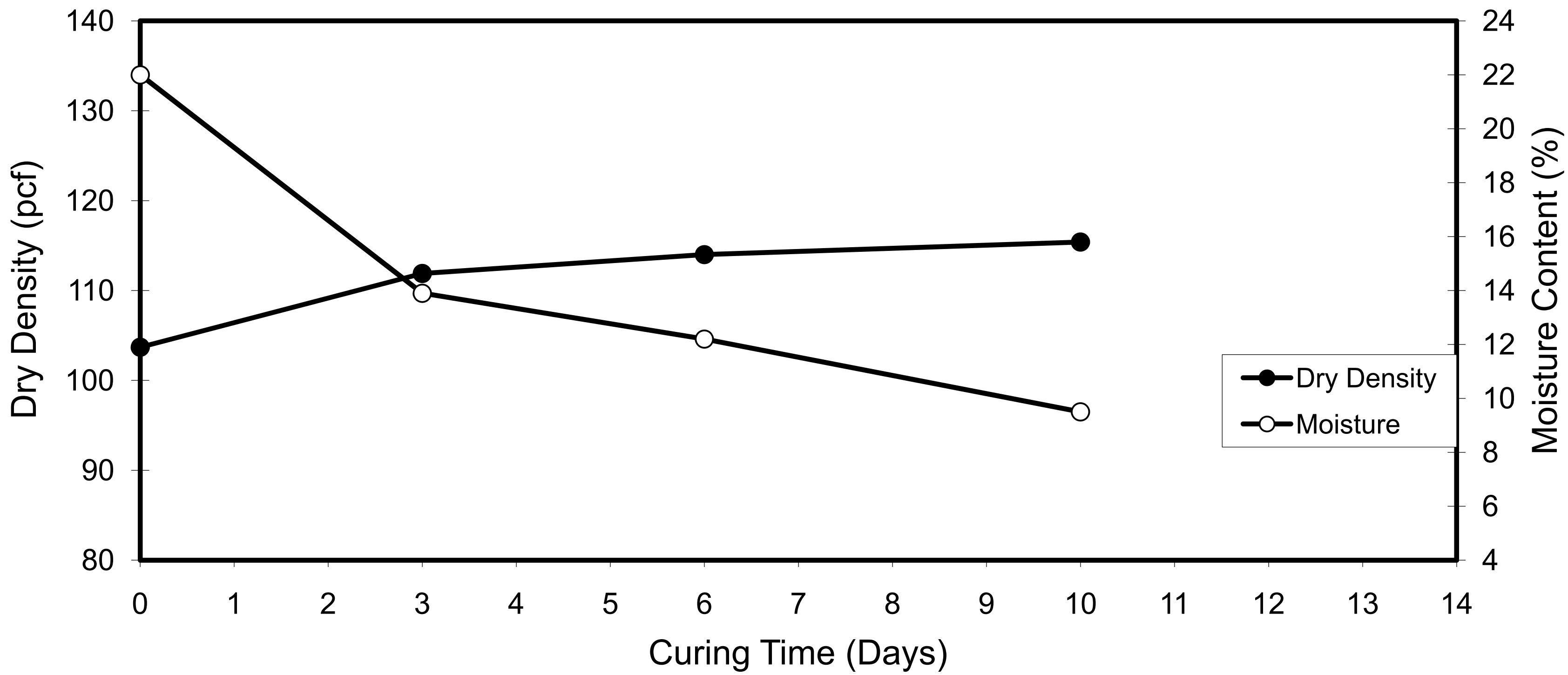


Figure 4.12e
Nuclear w - γ Gauge Readings
(Moisture Content and Dry Density)
for Country Club Road, Payne County, Ok

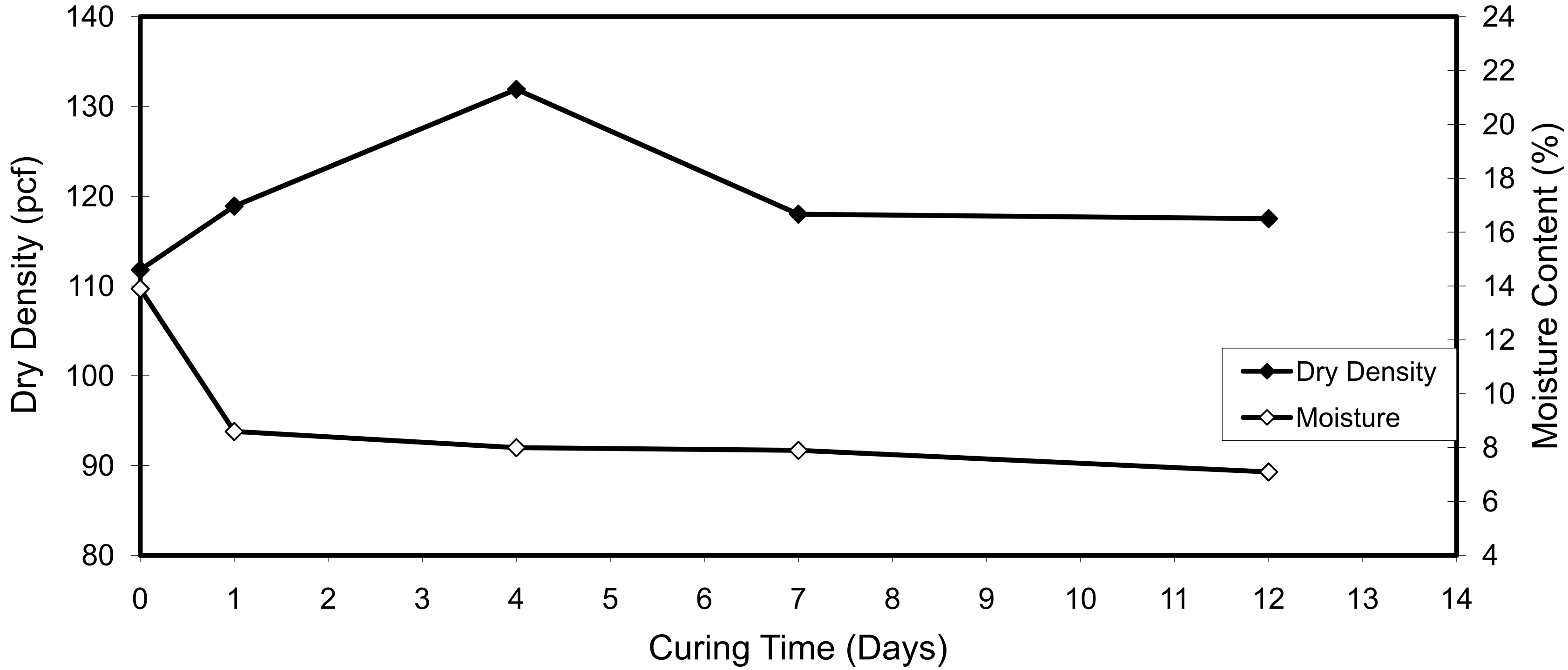


Figure 4.13a
Stiffness Gauge Readings (K and E)
for Oakdale Dr. - North, Enid, Ok

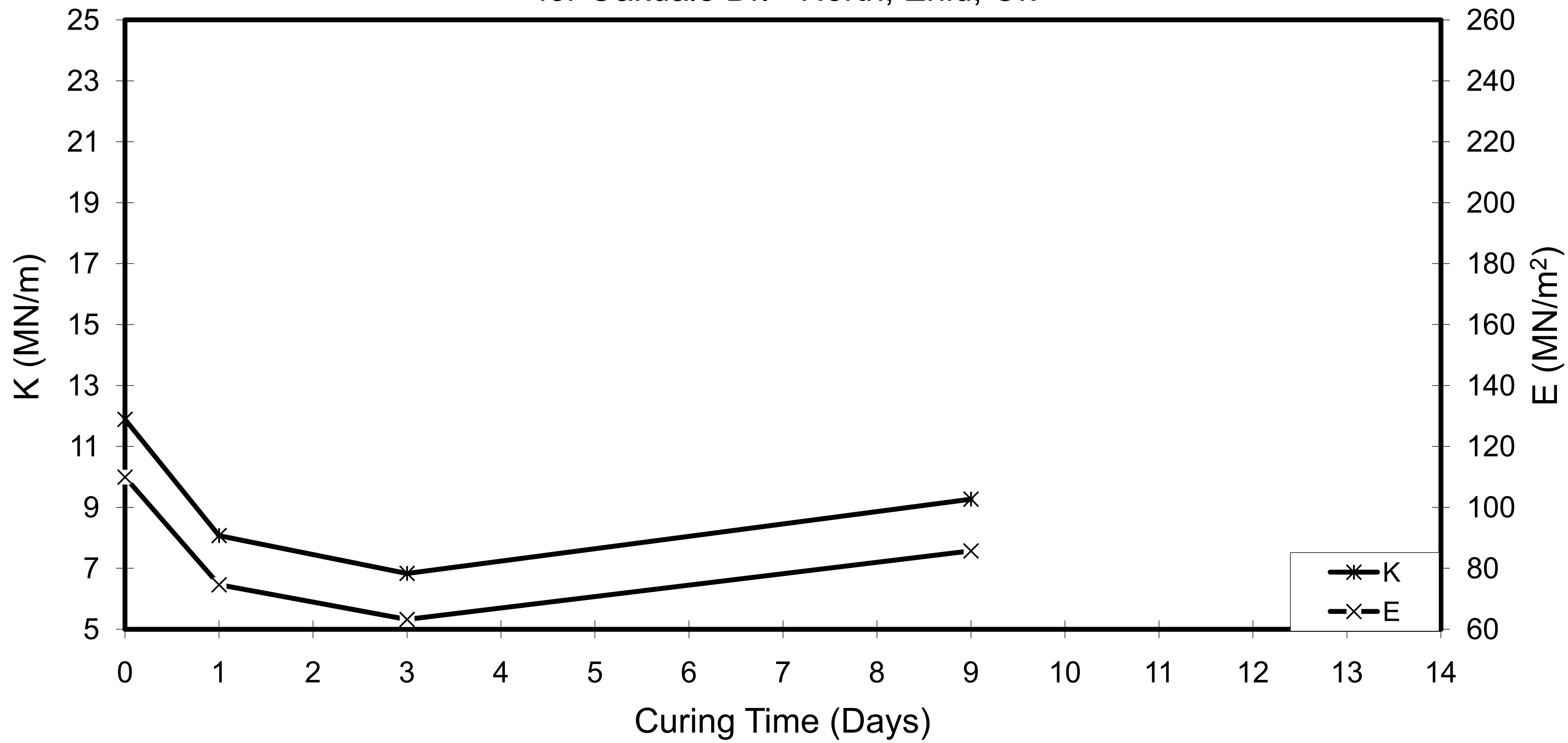


Figure 4.13b
Stiffness Gauge Readings (K and E)
for Oakdale Dr. - South, Enid, Ok

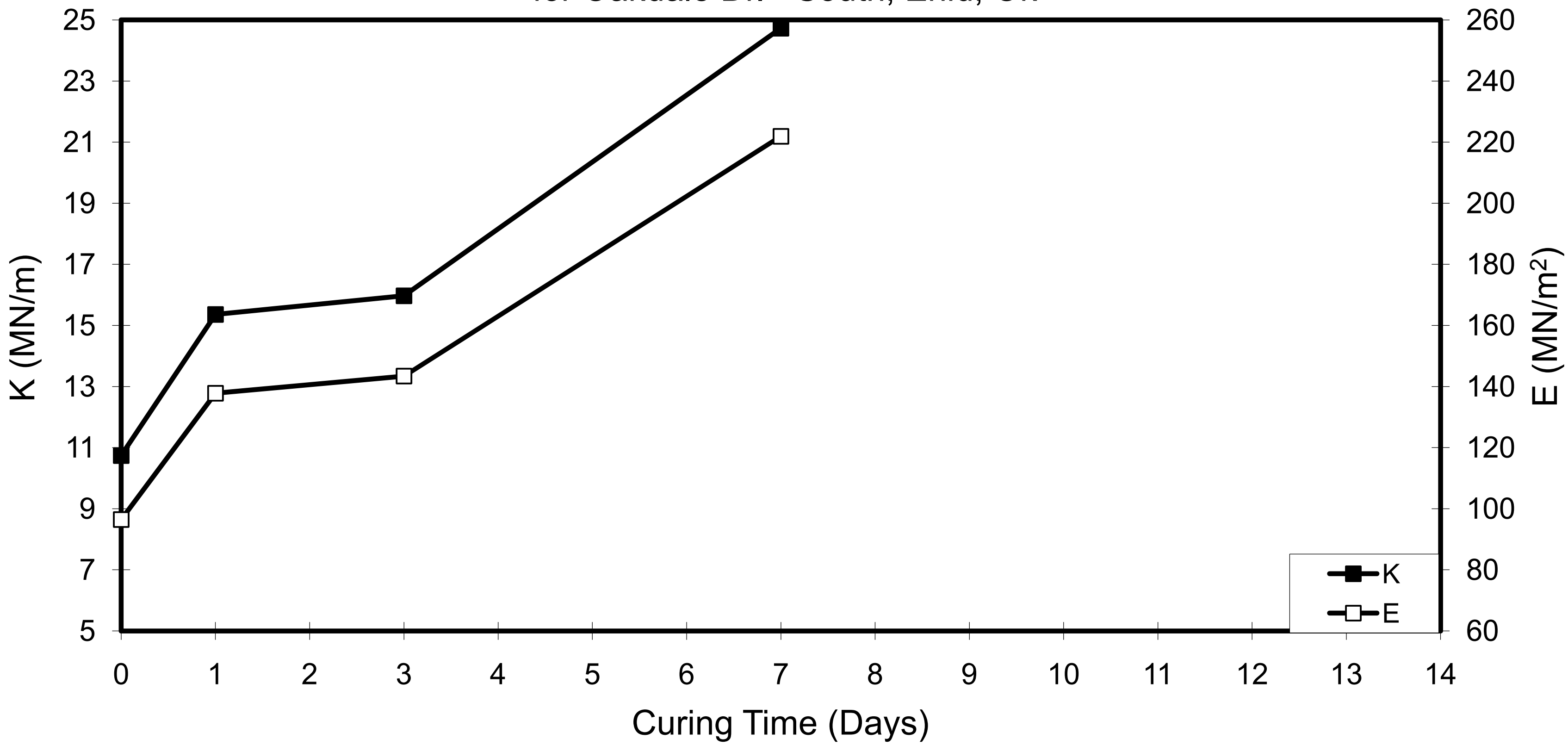


Figure 4.13c
Stiffness Gauge Readings (K and E)
for U.S. 62, Anadarko, Ok

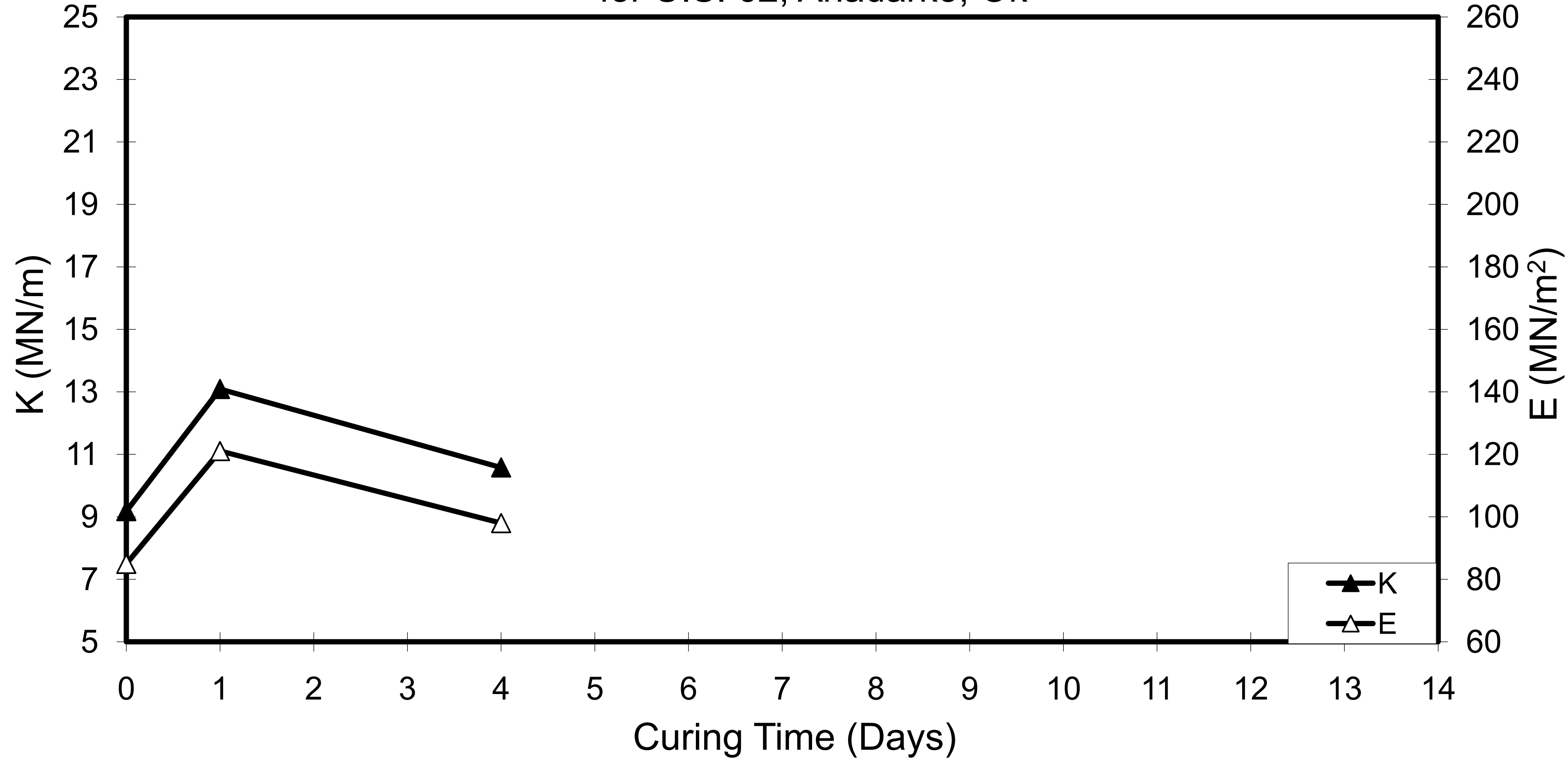


Figure 4.13d
Stiffness Gauge Readings (K and E)
for 15th Street, Perry, Ok

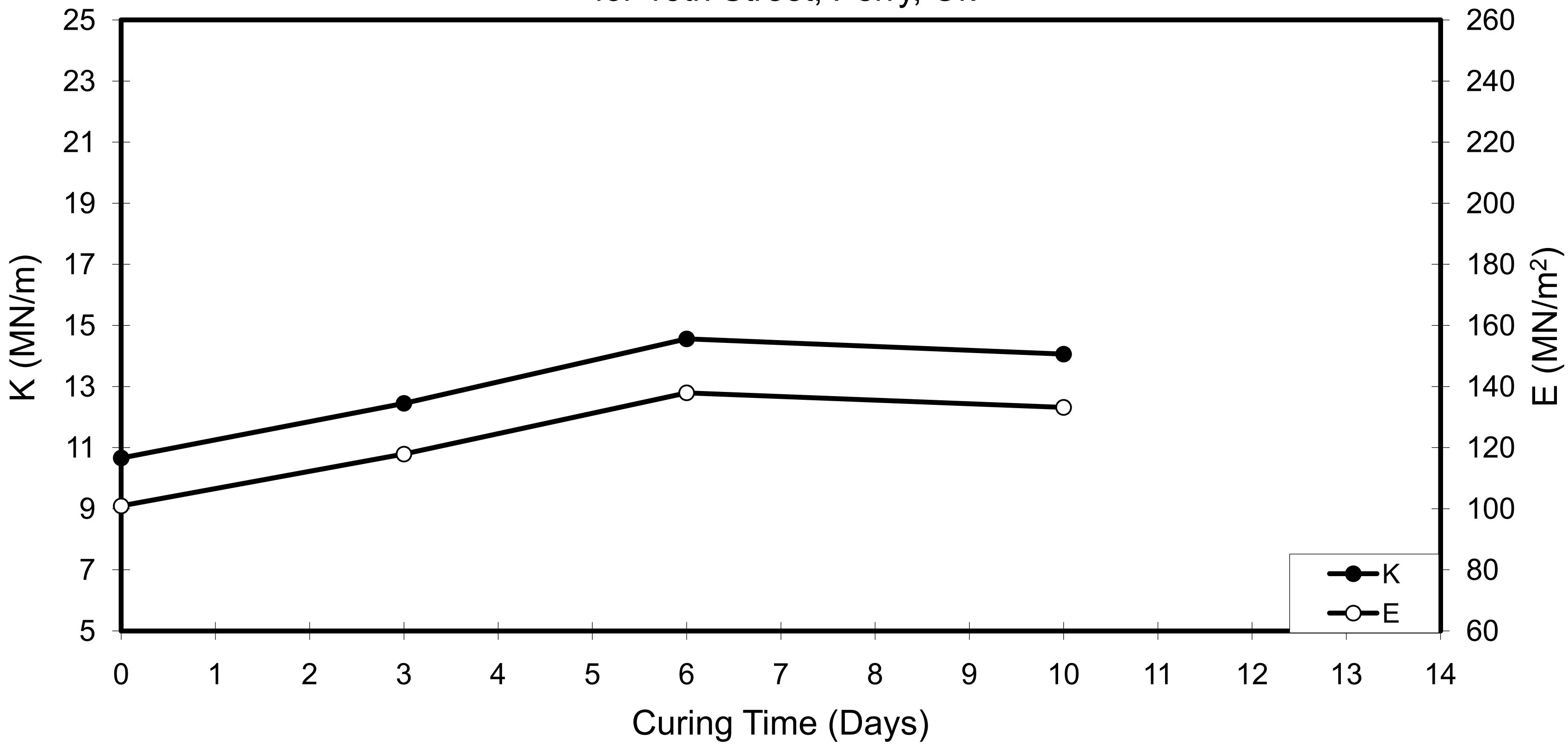
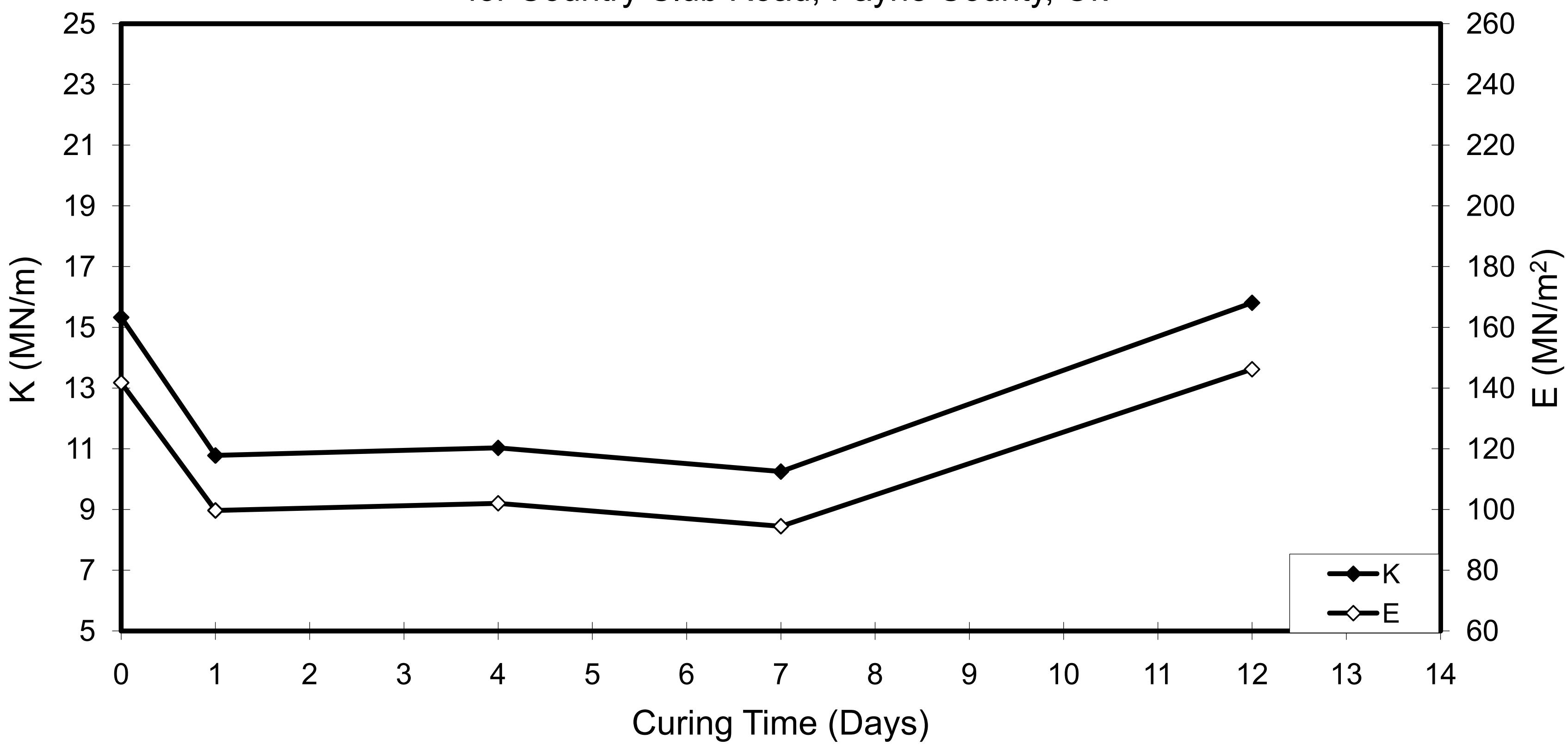


Figure 4.13e
Stiffness Gauge Readings (K and E)
for Country Club Road, Payne County, Ok



FWD Modulus (E_{vd})

Figure 4.14a, b, c, d, and e show the modulus, E_{vd}, (e.g. elastic) data collected using a Zorn 2000 Portable Falling Weight Deflectometer (FWD). The E_{vd} with curing time trends are generally consistent increasing with curing time. Again the rates of increase are more modest than laboratory testing. The FWD modulus values are typically less than one-half the value calculated from the stiffness gauge data, probably because of the way modulus (or stiffness) were measured.

Dynamic Cone Penetration

Figures 4.15a, b, c, d, and e show dynamic cone penetration (DCP) test data presented in terms of the Dynamic Cone Index (DCI). The trends with curing time are generally consistent, that is, decreasing and leveling off with curing time. The only exception is U.S. 62, Anadarko where the DCI increased slightly following treatment which was due to the strong stiff nature of the untreated soils.

Figures 4.16a, b, c, d, and e show calculated values of CBR and M_R based on DCI data. The following relationships were used to calculate the values:

$$CBR = \frac{292}{DCI^{1.12}} \qquad \text{(DCI in mm/blow)}$$

and

$$CBR = 1500\ CBR$$

As with the DCI data, the trends with curing time are consistent with curing time showing increases in both CBR and M_R then leveling off.

PANDA Penetrometer

Figures 4.17a, b, c, d, and e show the average PANDA Penetrometer tip resistance data measured from a soil solutions PANDA Penetrometer in MN/m^2 for the treated subgrade soil layer. The data are generally consistent with the tip resistance increasing then leveling off with curing time.

Figure 4.14a
Portable FWD Modulus (E_{vd})
for Oakdale Dr. - North, Enid, Ok

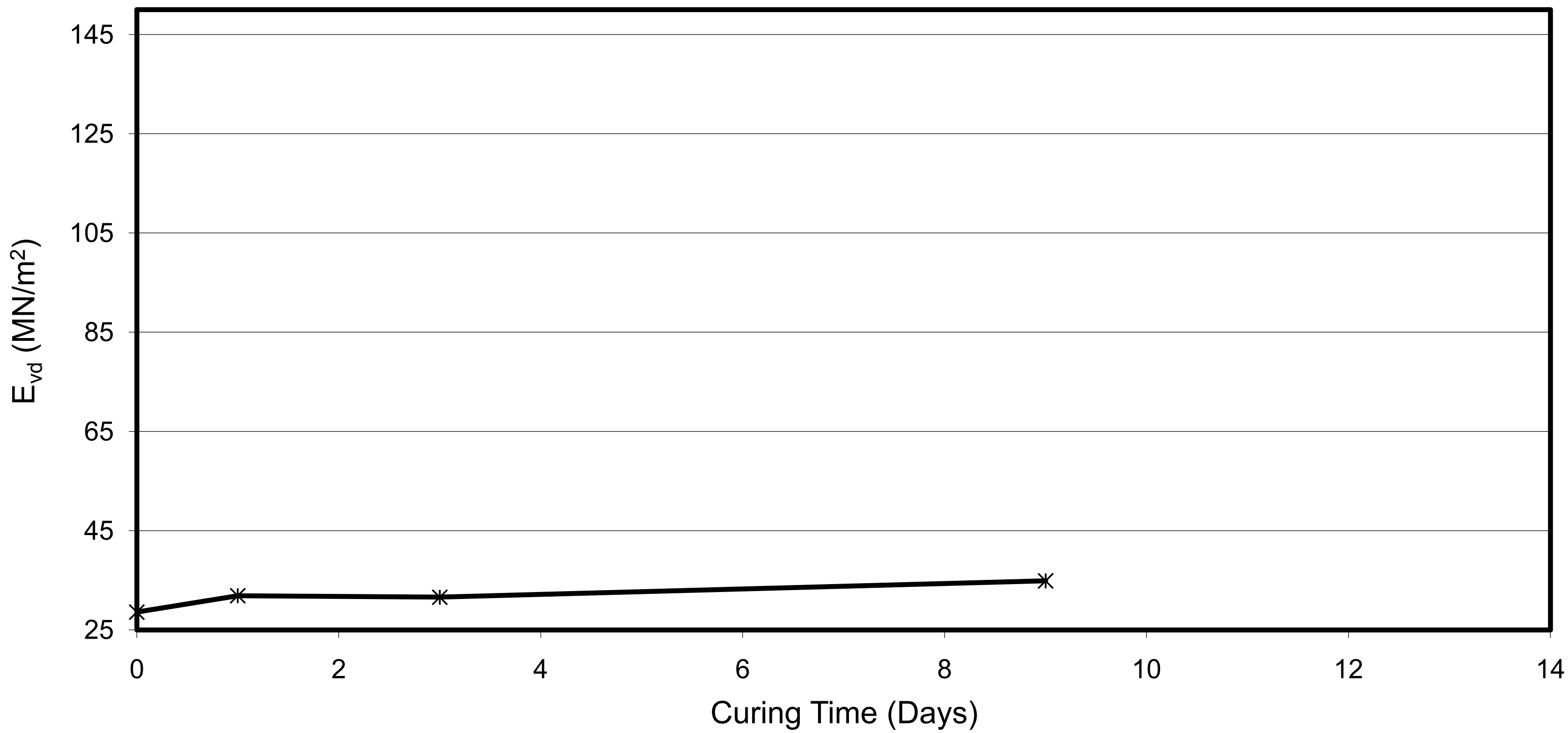


Figure 4.14b
Portable FWD Modulus (E_{vd})
for Oakdale Dr. - South, Enid, Ok

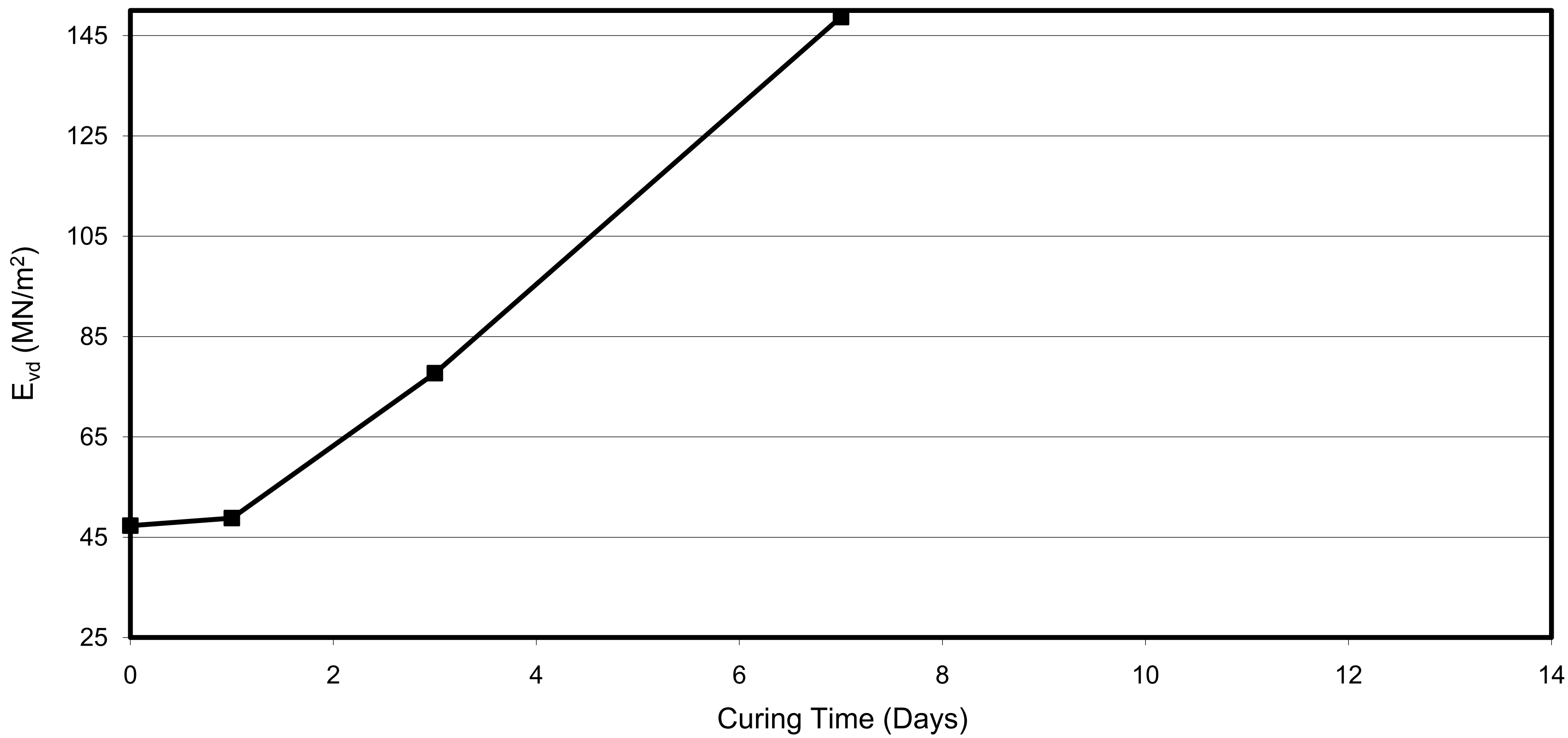


Figure 4.14c
Portable FWD Modulus (E_{vd})
for U.S. 62, Anadarko, Ok

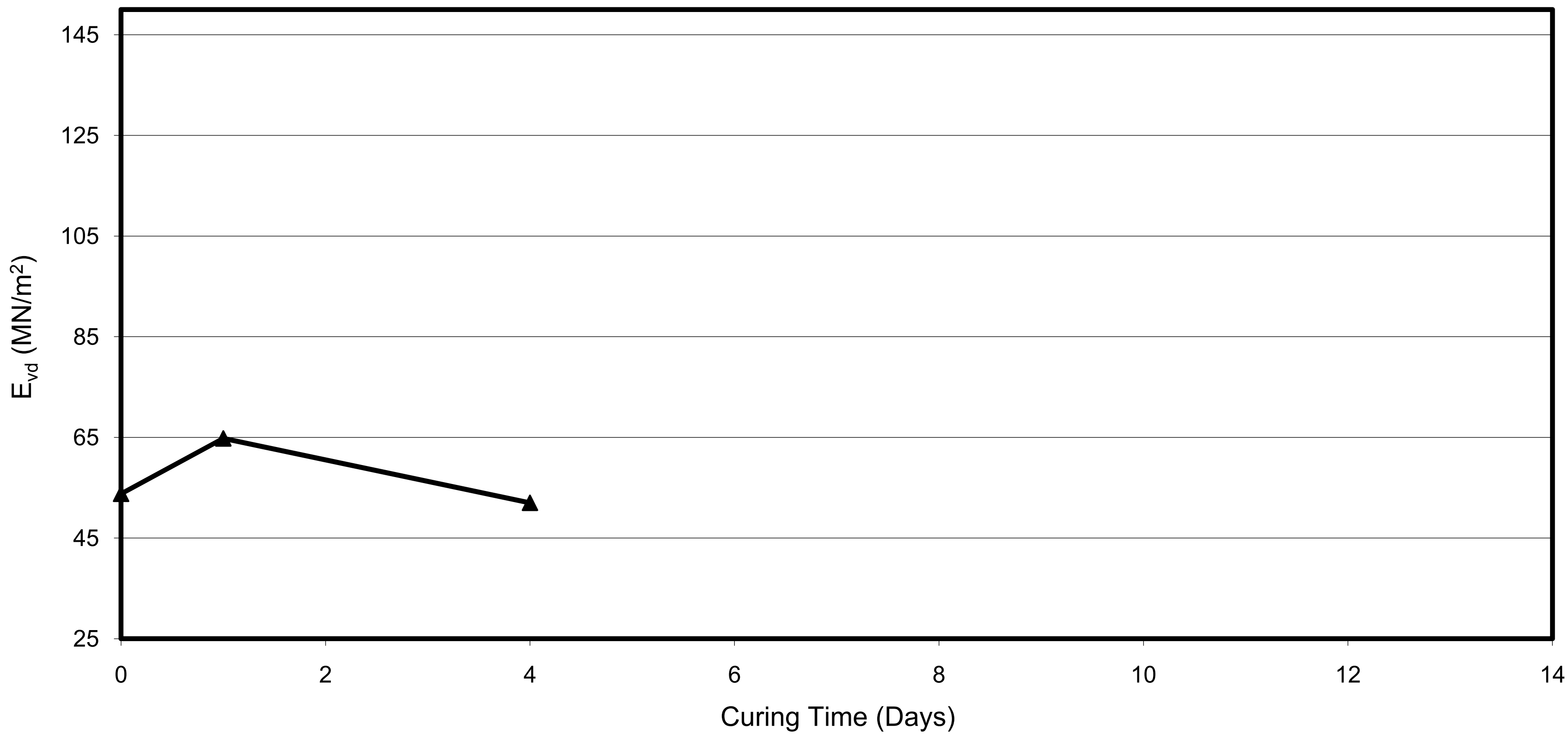


Figure 4.14d
Portable FWD Modulus (E_{vd})
for 15th Street, Perry, Ok

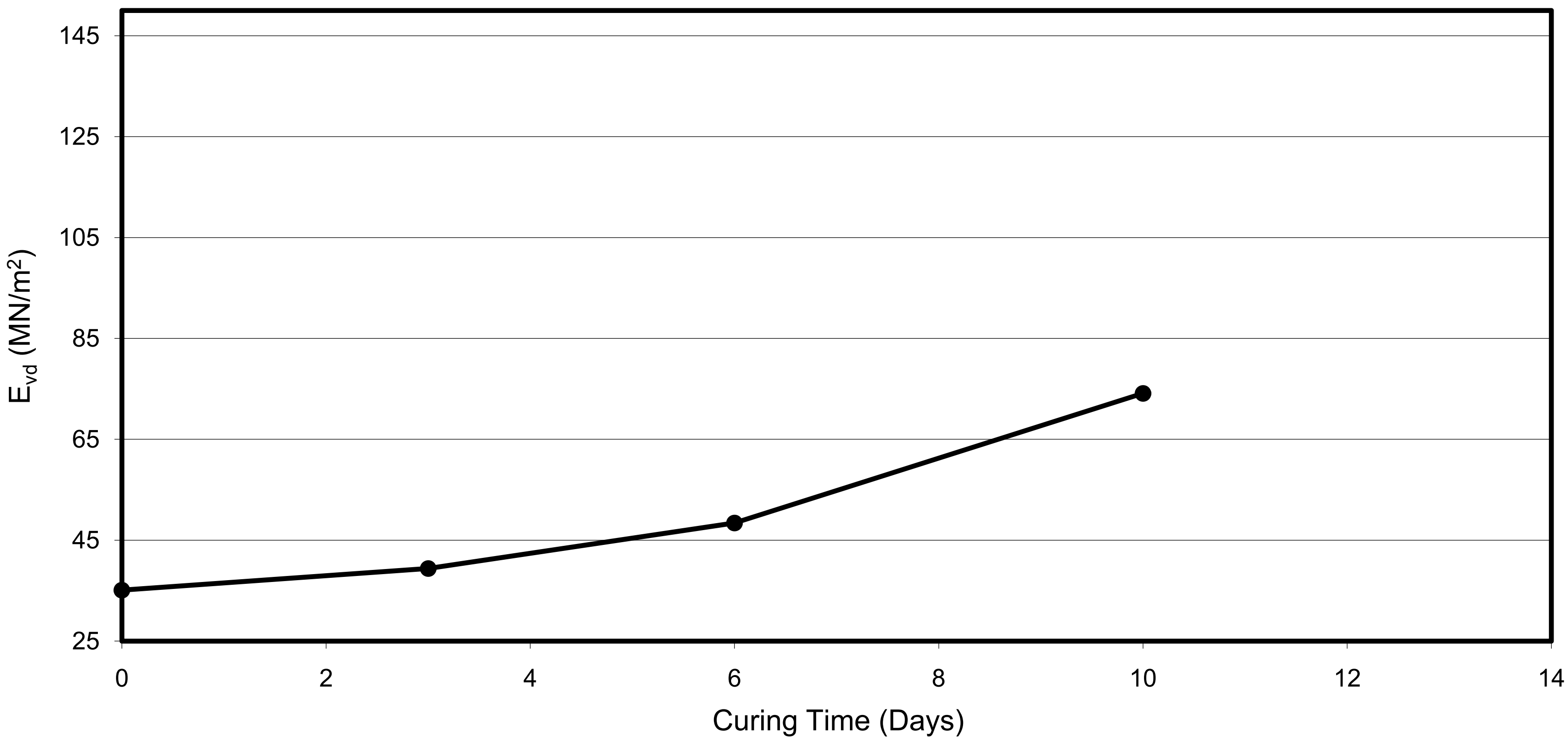


Figure 4.14e
Portable FWD Modulus (E_{vd})
for Country Club Road, Payne County, Ok

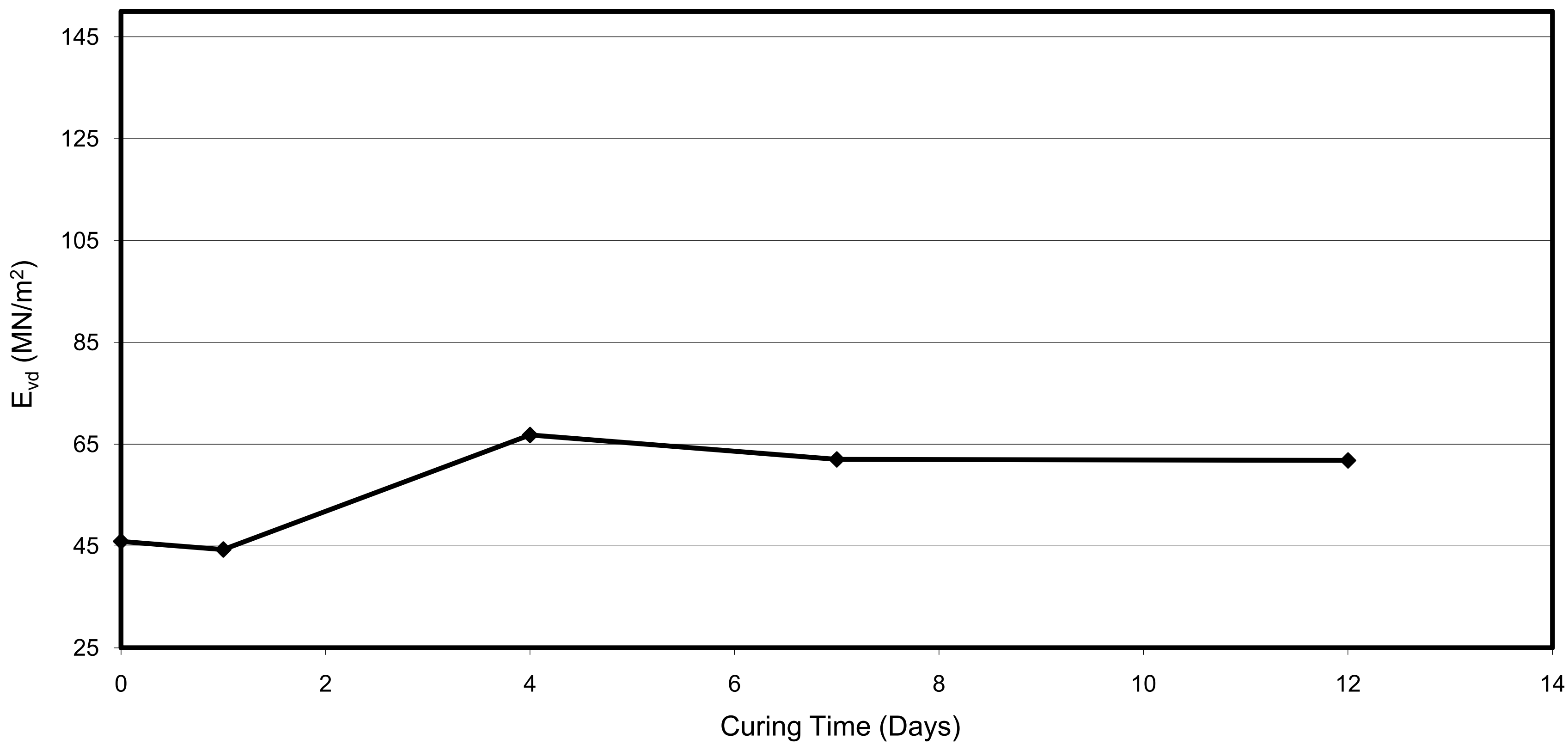


Figure 4.15a
Dynamic Cone Penetration Test - Cone Index (DCI)
for Oakdale Dr. - North, Enid, Ok

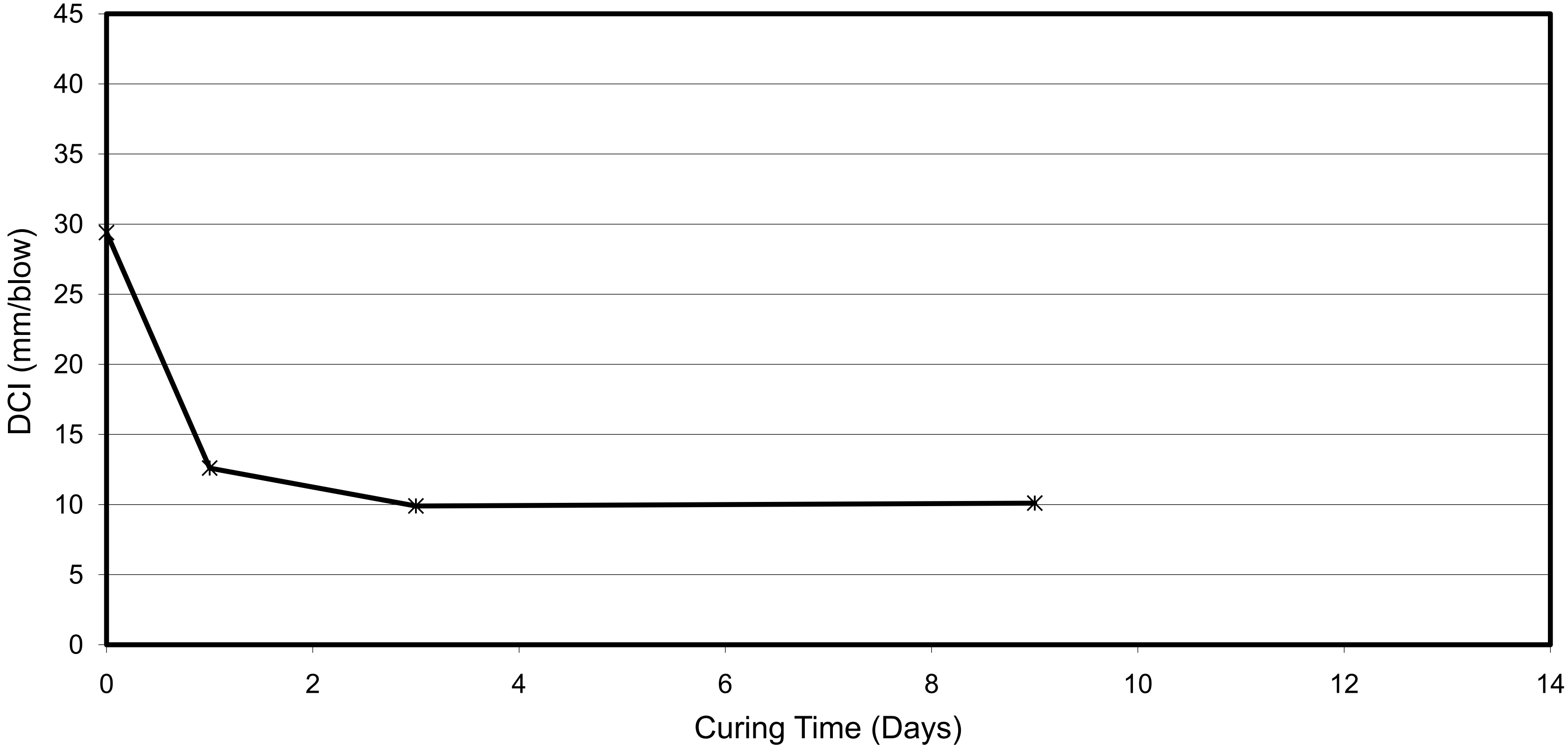


Figure 4.15b
Dynamic Cone Penetration Test - Cone Index (DCI)
for Oakdale Dr. - South, Enid, Ok

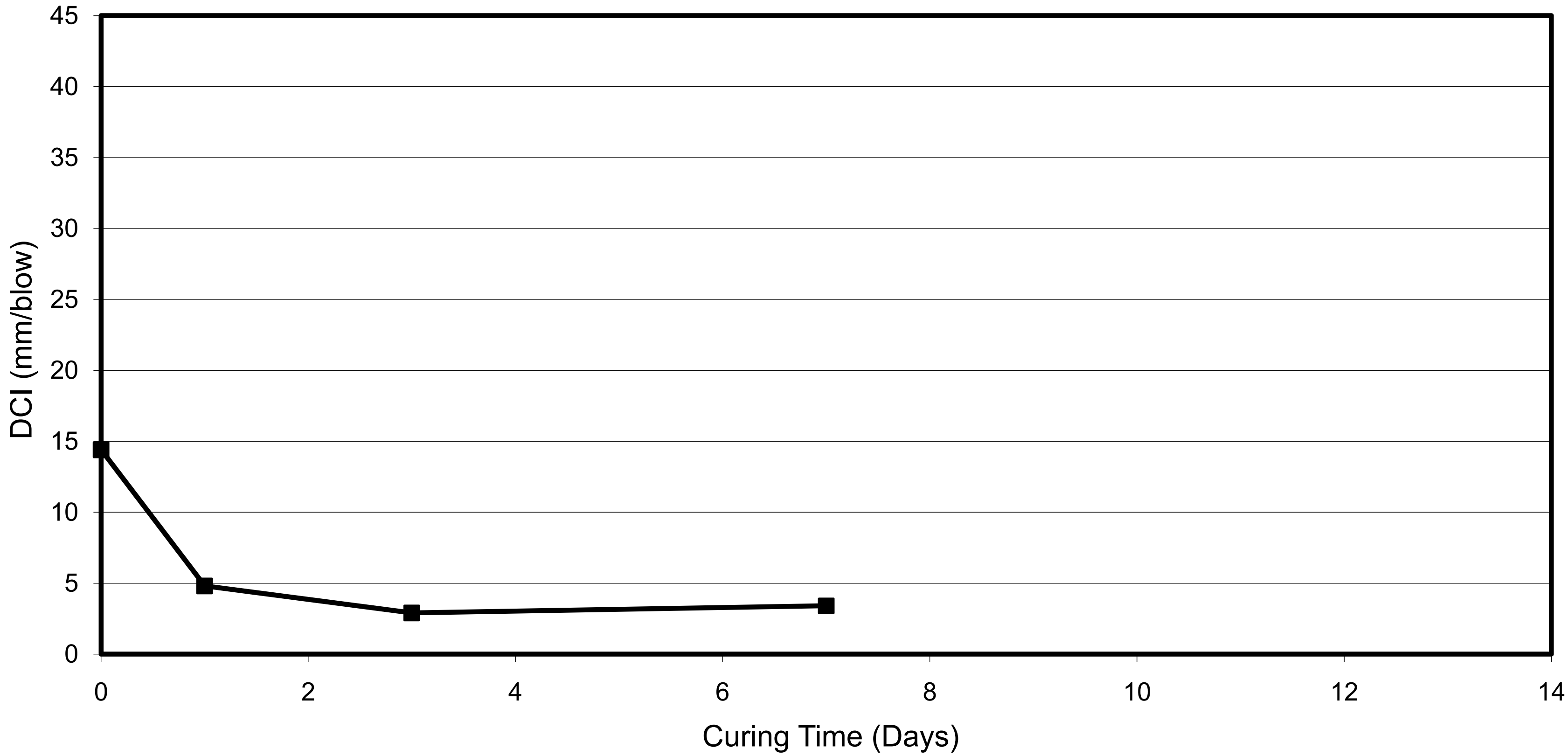


Figure 4.15c
Dynamic Cone Penetration Test - Cone Index (DCI)
for U.S. 62, Anadarko, Ok

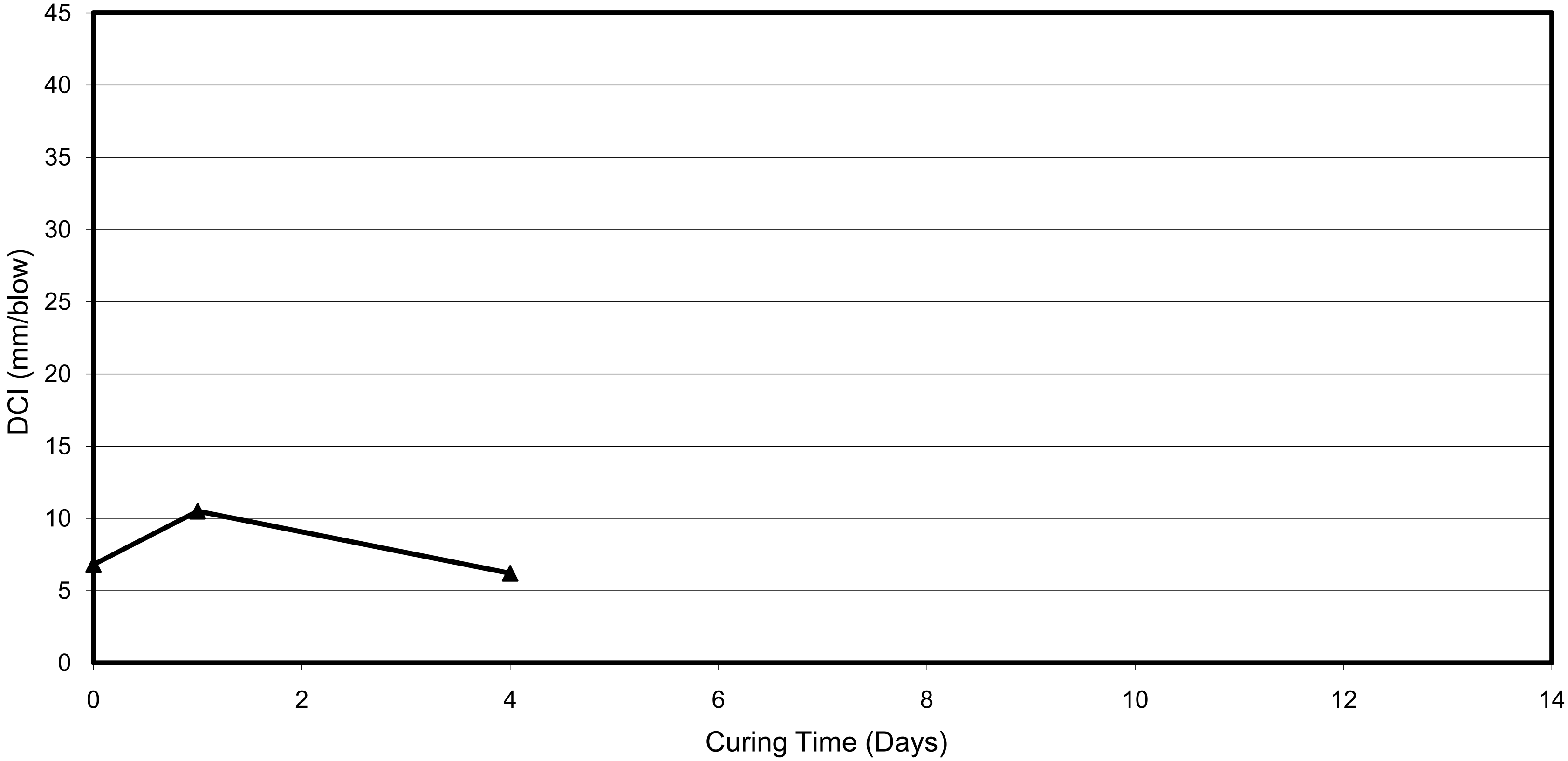


Figure 4.15d
Dynamic Cone Penetration Test - Cone Index (DCI)
for 15th Street, Perry, Ok

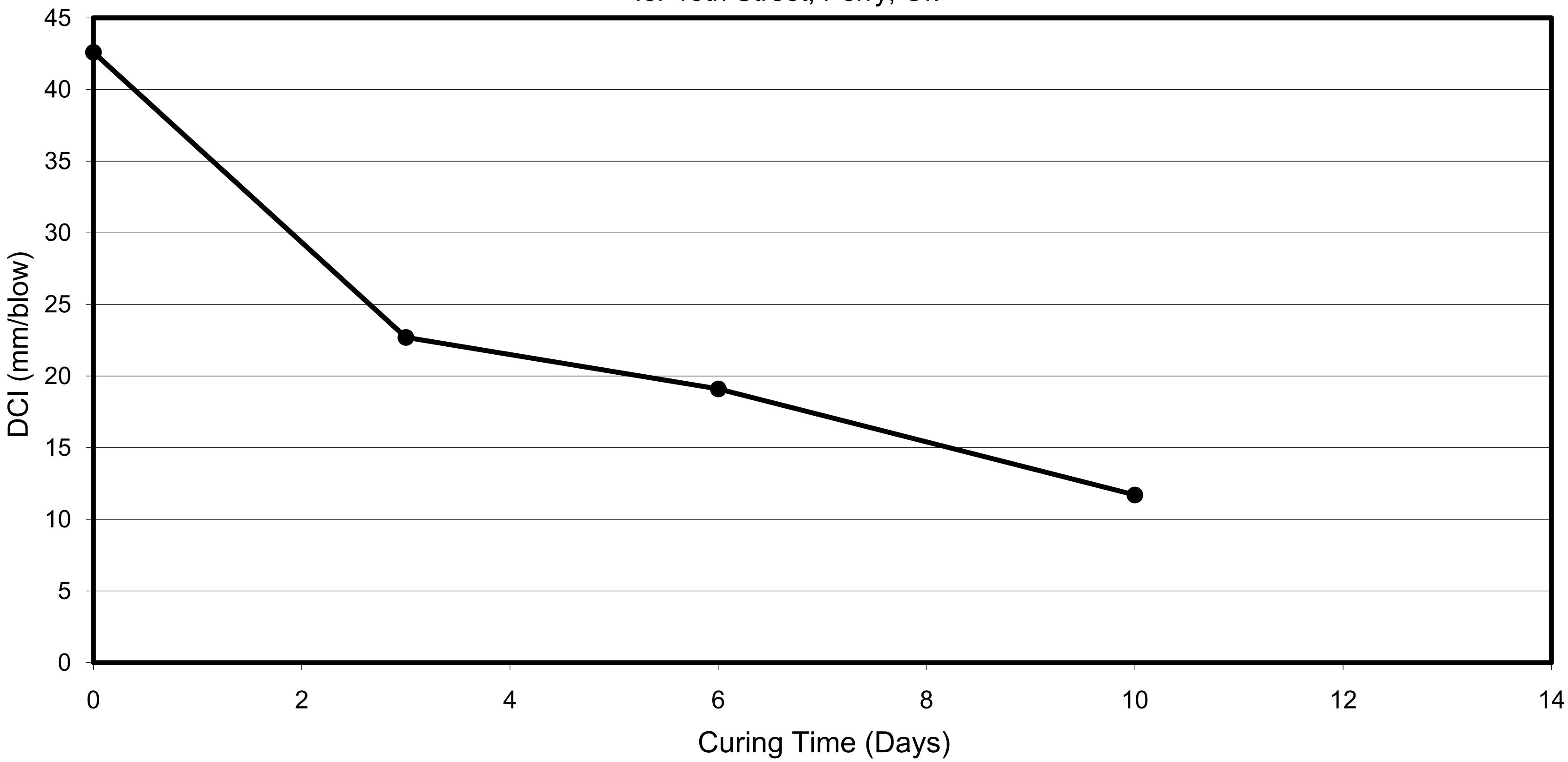


Figure 4.15e
Dynamic Cone Penetration Test - Cone Index (DCI)
for Country Club Road, Payne County, Ok

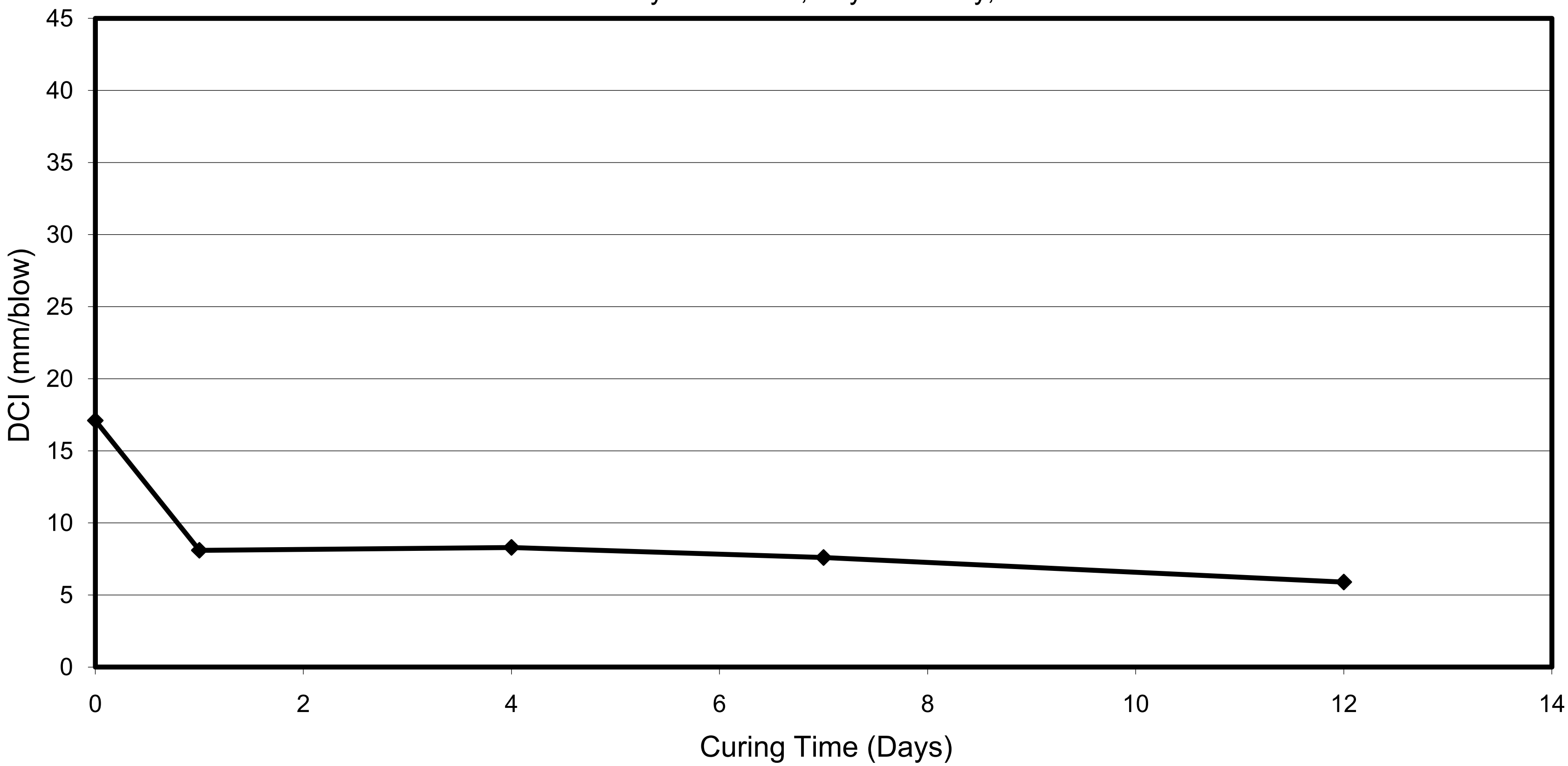


Figure 4.16a
Dynamic Cone Penetration Test Calculated CBR and MR
for Oakdale Dr. - North, Enid, Ok

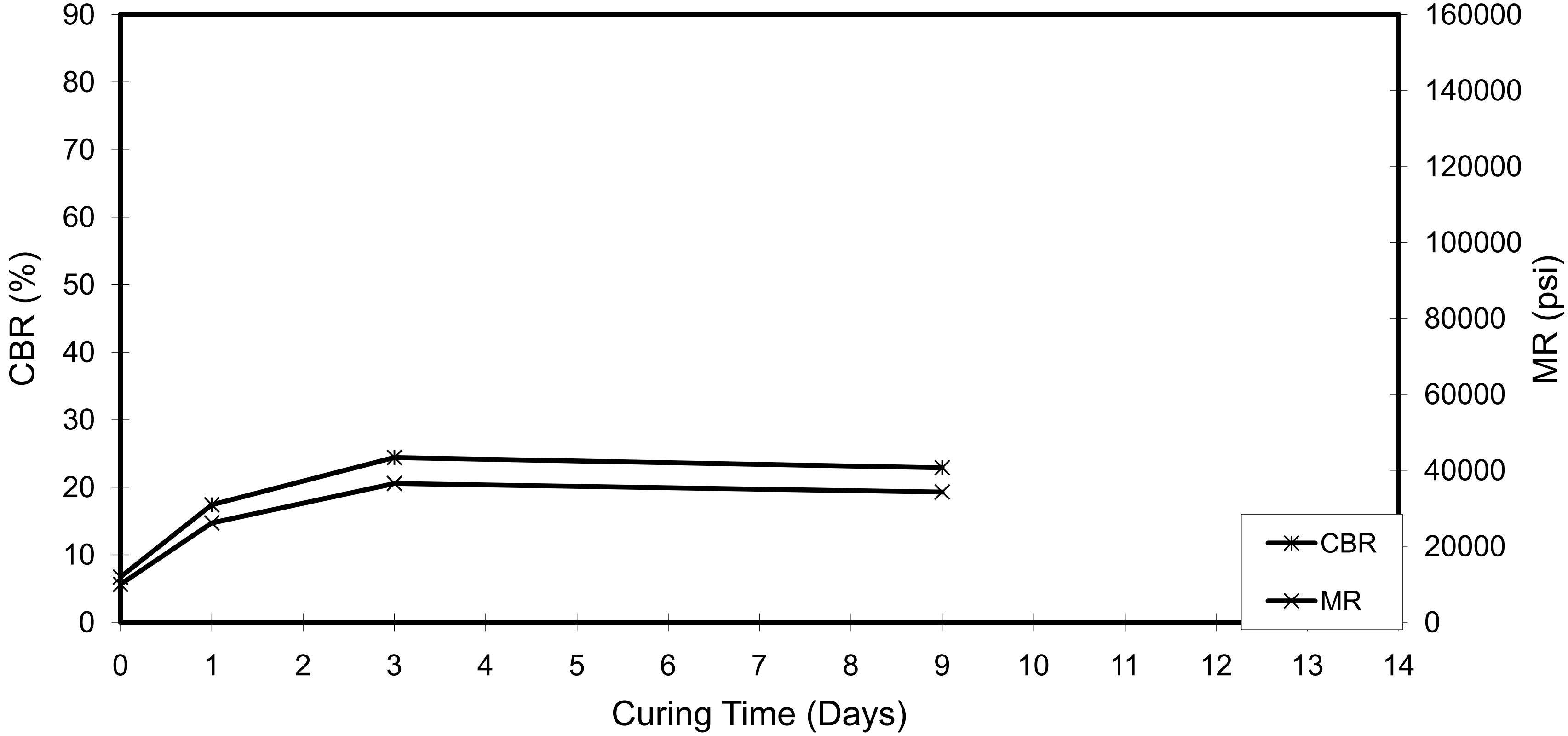


Figure 4.16b
Dynamic Cone Penetration Test Calculated CBR and MR
for Oakdale Dr. - South, Enid, Ok

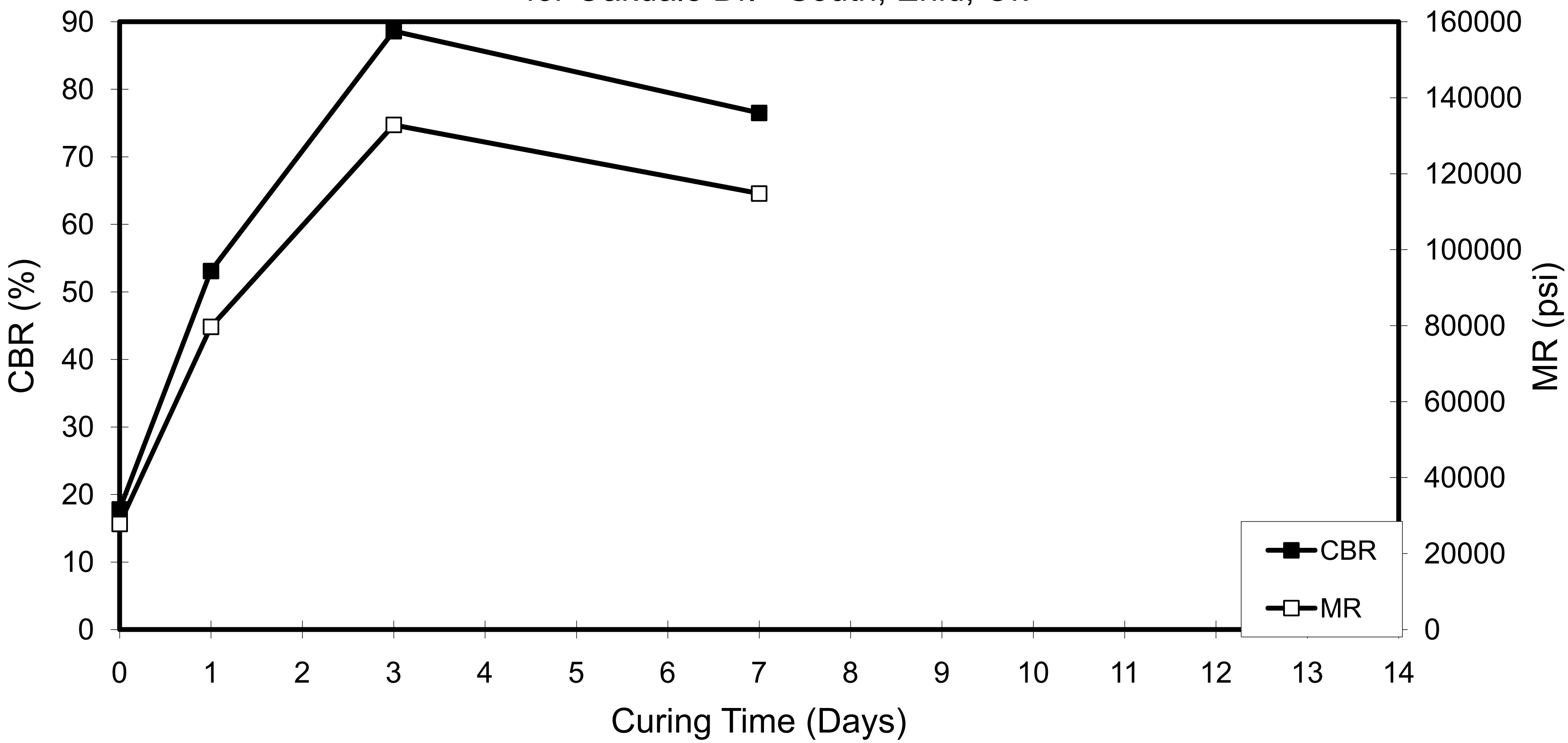


Figure 4.16c
Dynamic Cone Penetration Test Calculated CBR and MR
for U.S. 62, Anadarko, Ok

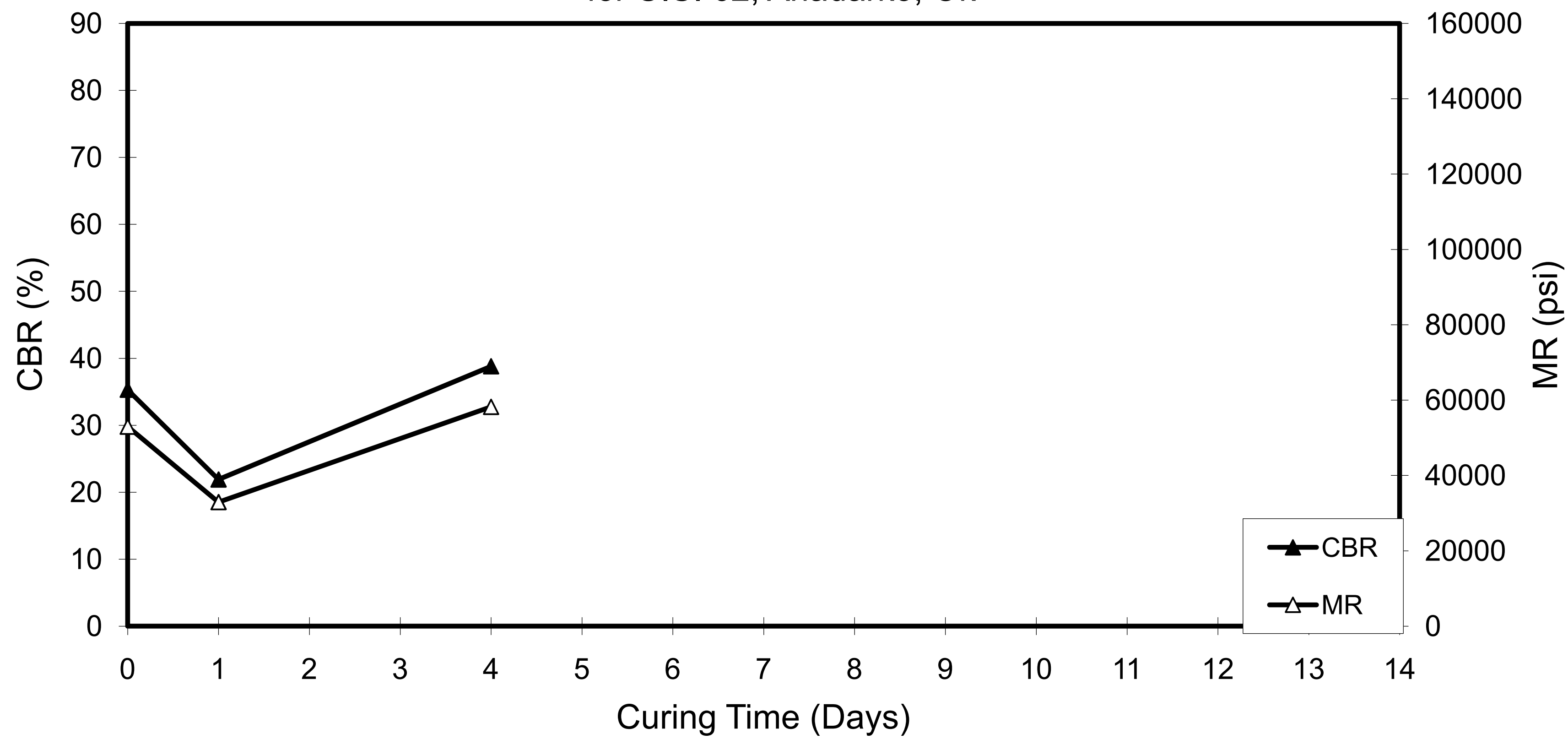


Figure 4.16d
Dynamic Cone Penetration Test Calculated CBR and MR
for 15th Street, Perry, Ok

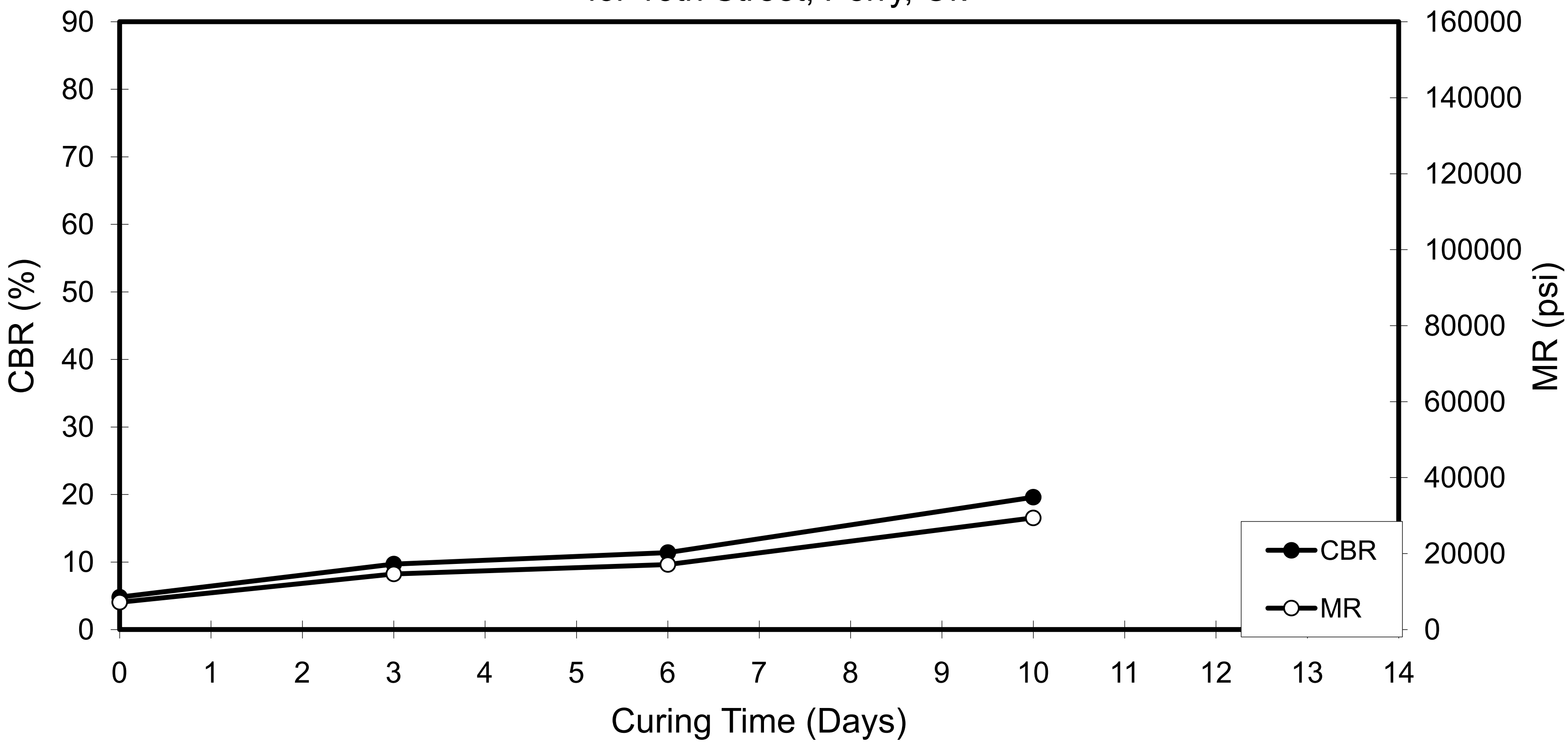
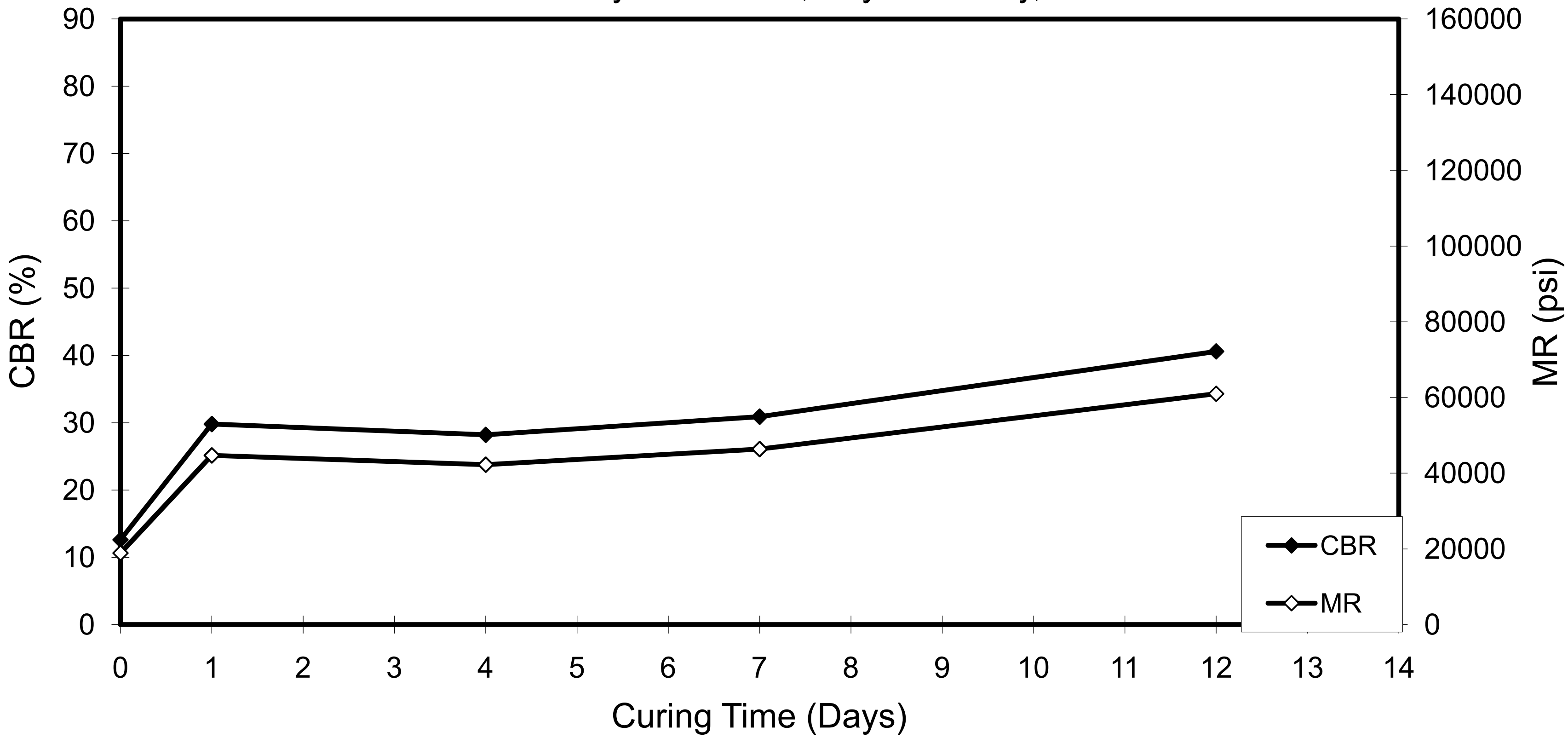


Figure 4.16e
Dynamic Cone Penetration Test Calculated CBR and MR
for Country Club Road, Payne County, Ok



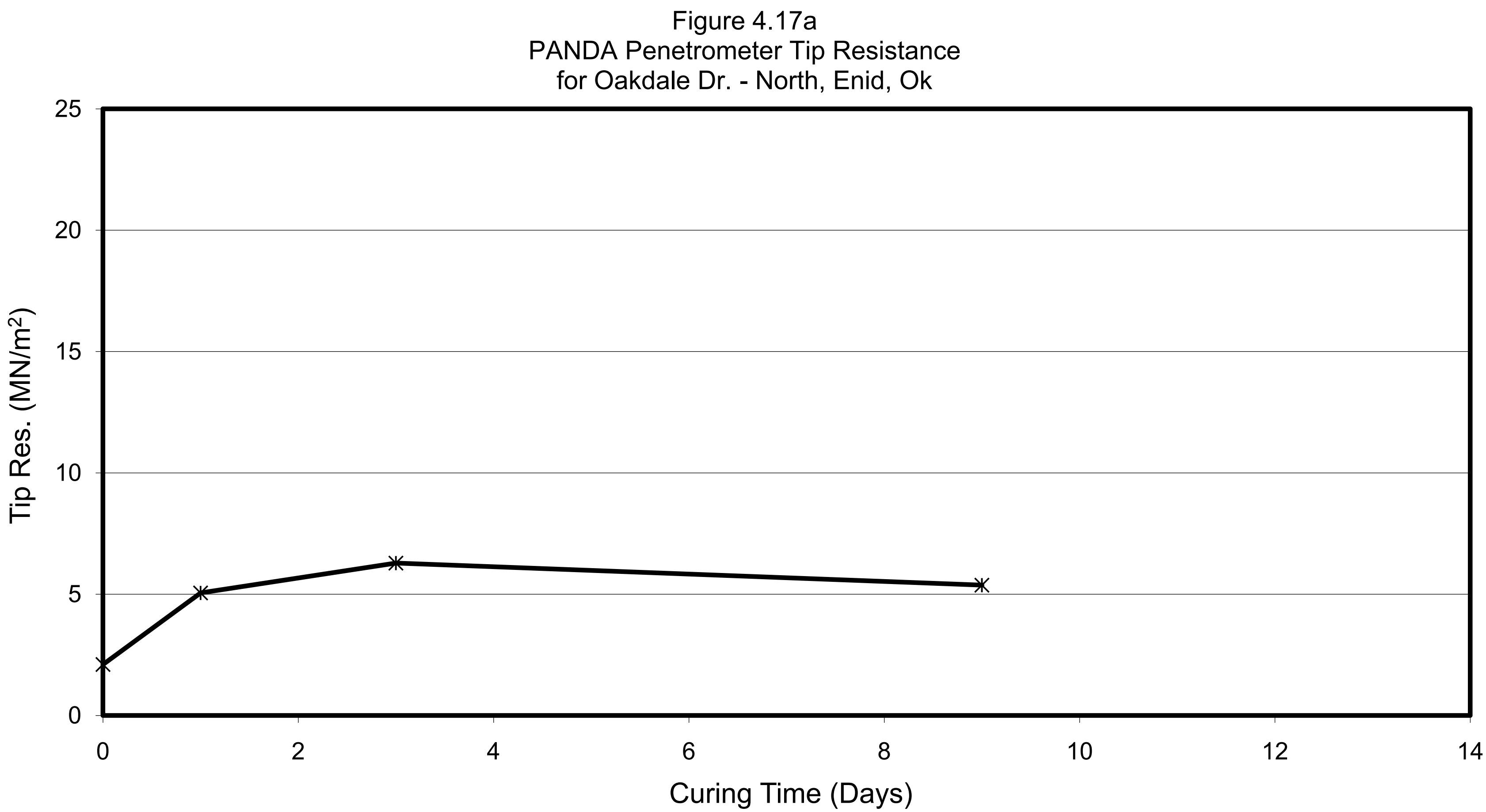


Figure 4.17a
PANDA Penetrometer Tip Resistance
for Oakdale Dr. - North, Enid, Ok
Tip Res. (MN/m2)
Curing Time (Days)
0
5
10
15
20
25
0
2
4
6
8
10
12
14

Figure 4.17b
PANDA Penetrometer Tip Resistance
for Oakdale Dr. - South, Enid, Ok

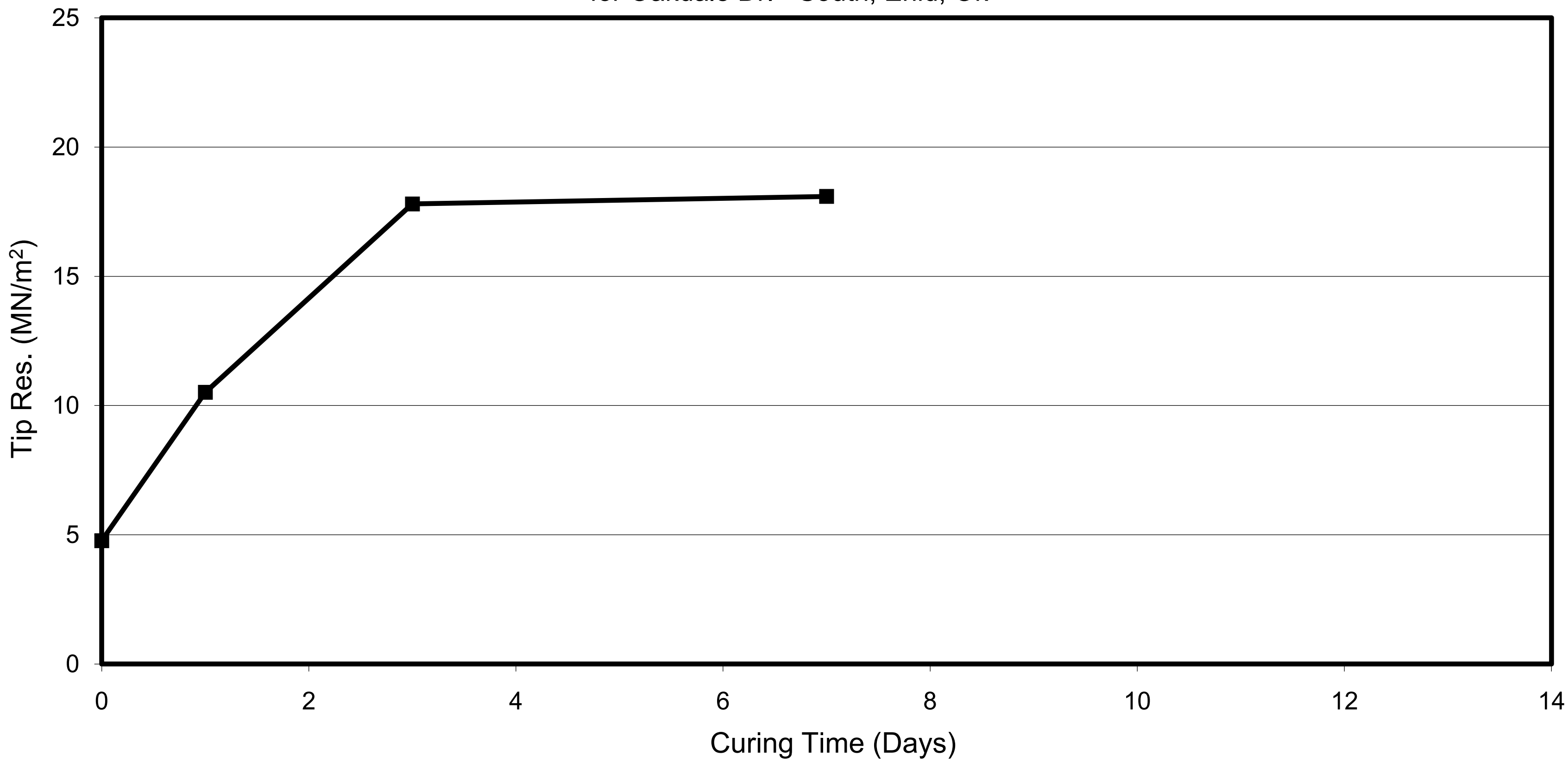


Figure 4.17c
PANDA Penetrometer Tip Resistance
for U.S. 62, Anadarko, Ok

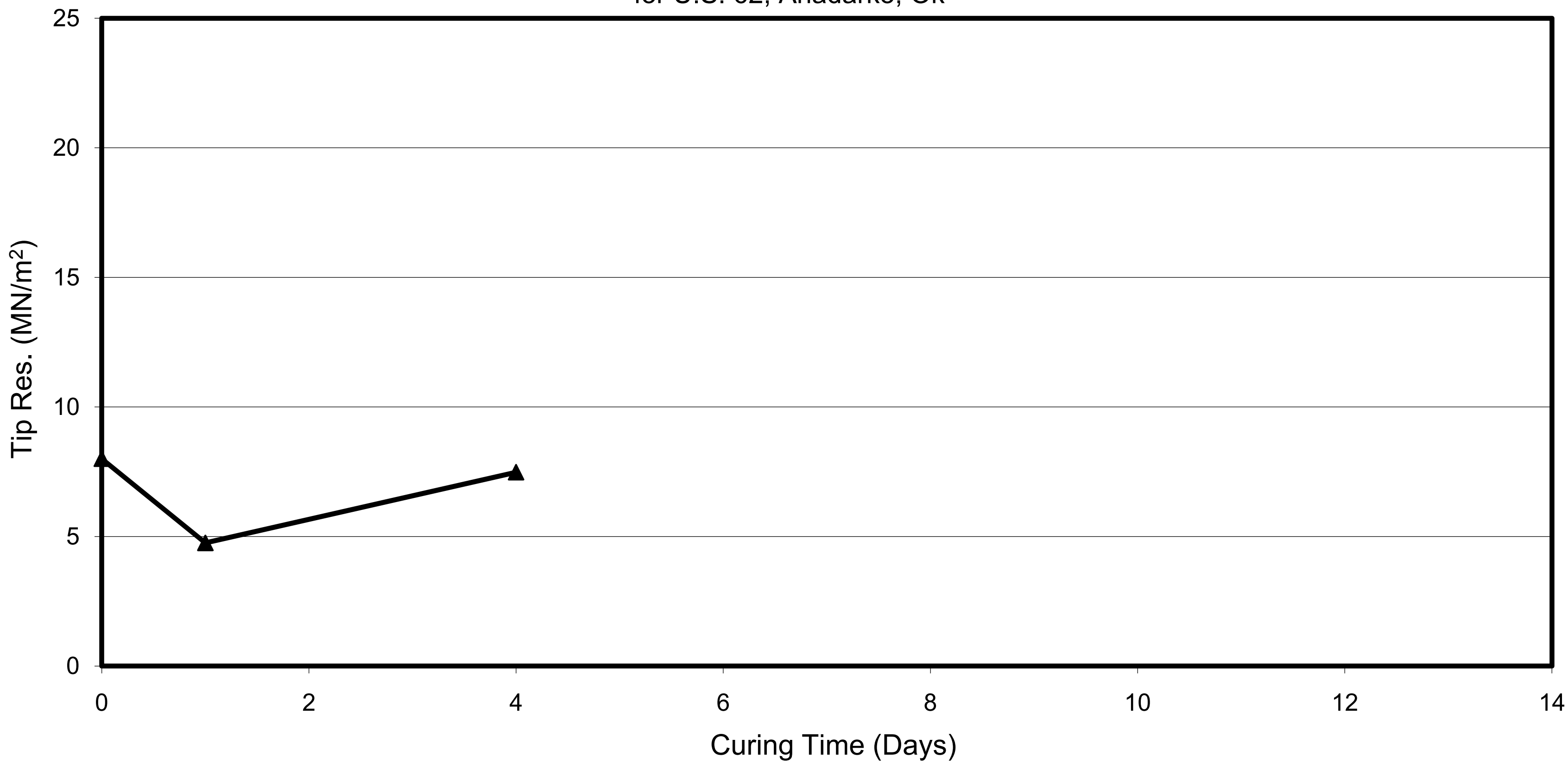


Figure 4.17d
PANDA Penetrometer Tip Resistance
for 15th Street, Perry, Ok

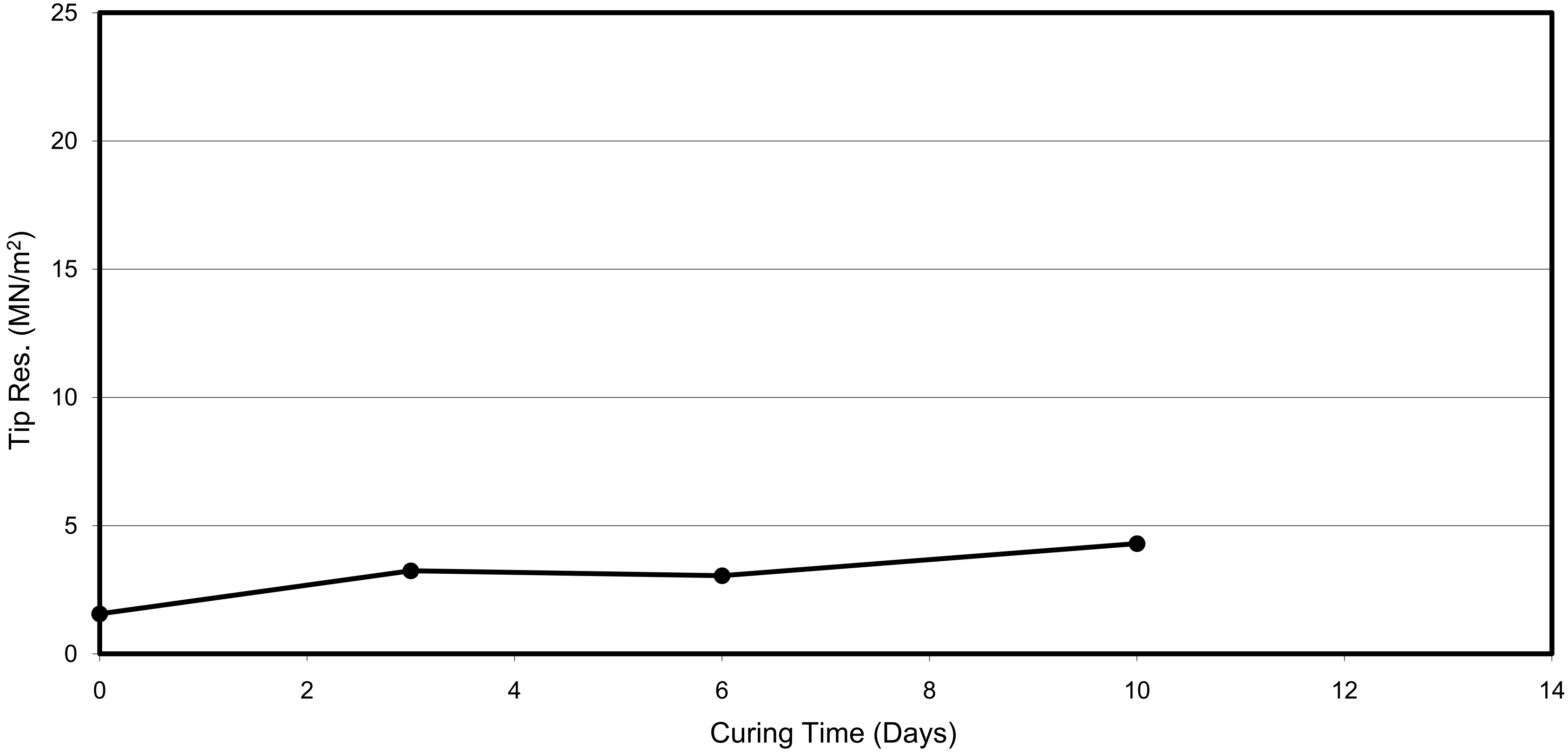
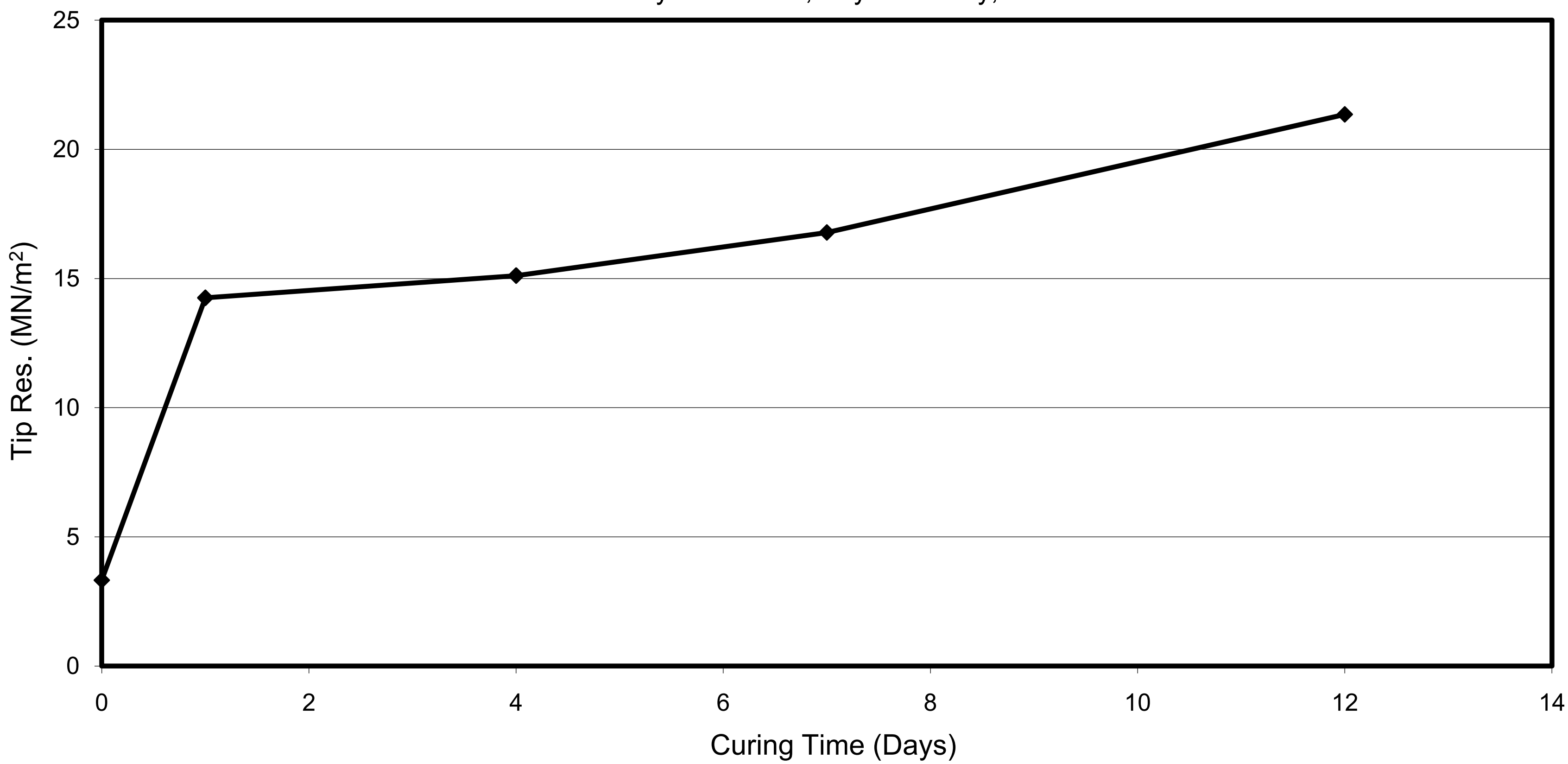


Figure 4.17e
PANDA Penetrometer Tip Resistance
for Country Club Road, Payne County, Ok



CHAPTER 5

EVALUATION AND DISCUSSION OF RESULTS

The purpose of this research project was to develop relationships between the magnitude and rate of development of strength improvement and pavement design input parameters for chemically stabilized subgrade soils. These relationships were used to confirm and/or adjust pavement design input parameters currently recommended in the AASHTO-MEPDG to reflect experiences with typical Oklahoma soils for common chemical additives used. In organizing and presenting the laboratory and field data for this project, several questions arose that needed to be addressed in order to achieve the purpose of the research. Specifically, these questions were:

1. How do the magnitudes of strength improvement compare for:
    a. Laboratory mixed vs. field mixed,
    b. Laboratory and field mixed vs. field data?
2. How do the rates of development of strength improvement compare for:
    a. Laboratory mixed vs. field mixed,
    b. Laboratory and field mixed vs. field data?
3. How do measured strength parameters, specifically M_R and E, compare to Level 2 correlation equations from AASHTO-MEPDG?

The discussion in the remainder of this chapter concentrates on answering these questions.

Magnitude and Rate of Strength Development

Figures 5.1a and 5.1b show UCS with curing time for all five field test sites for field mixed and laboratory mixed samples, respectively. The curves are typical of all stabilized soils treated with cementitious additives (e.g. CKD and FA), that is, an early development of strength, then a more gradual development with some leveling or dropping off. Subsequent discussion will concentrate on 7-day strength values because, with one exception, 70% or more of the strength increase occurred by 7 days curing. With the exception of field mixed samples from Country Club Road, Payne County, which had approximately twice the generally accepted application rate for fly ash, CKD stabilized soils exhibited higher UCS values. Some caution needs to be applied here because CKD performance (e.g. characteristics) varies with source (Miller, et al).

Figure 5.1a
Unconfined Compression Strength versus Curing Time for
Field Mixed Samples

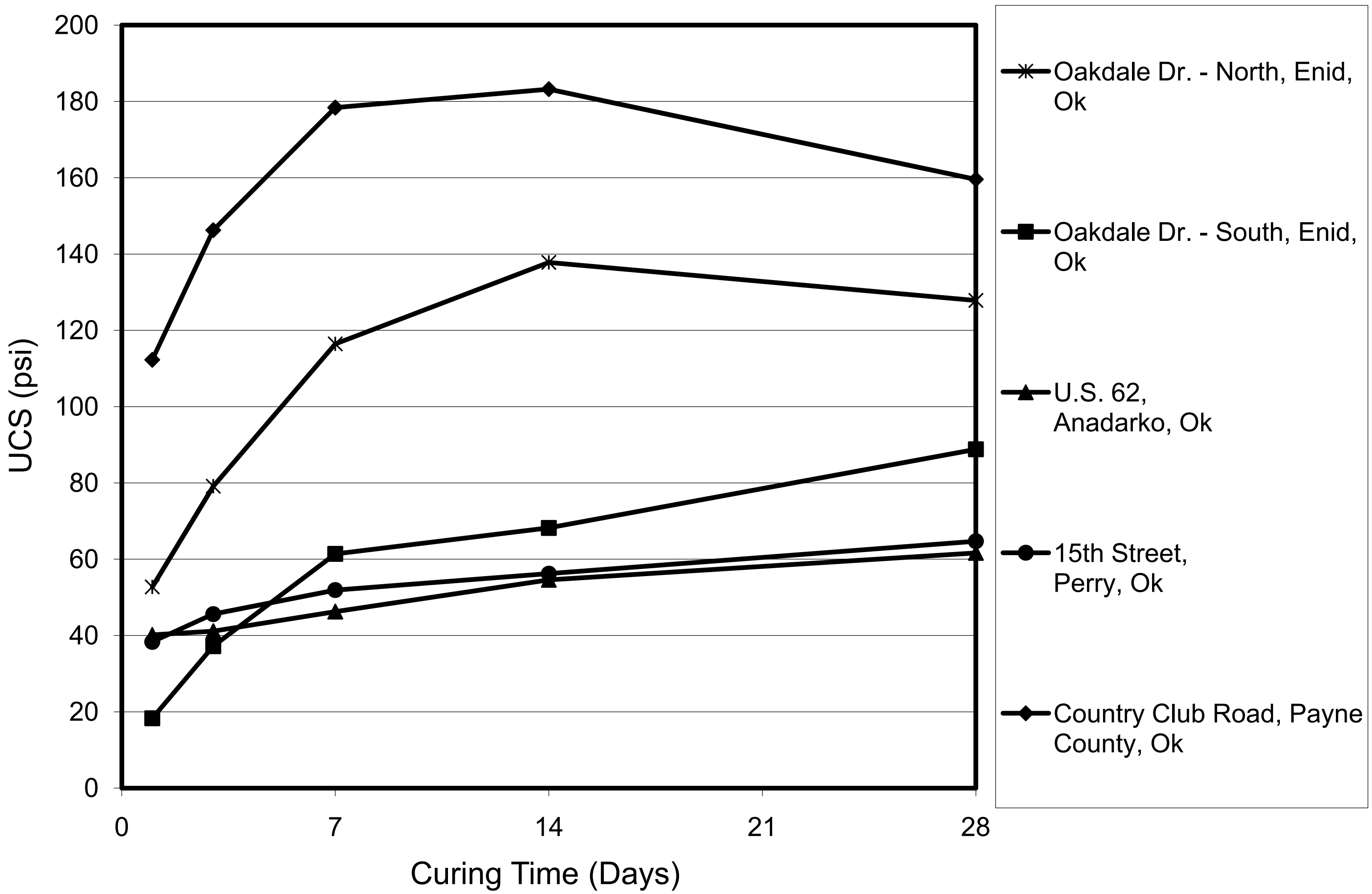
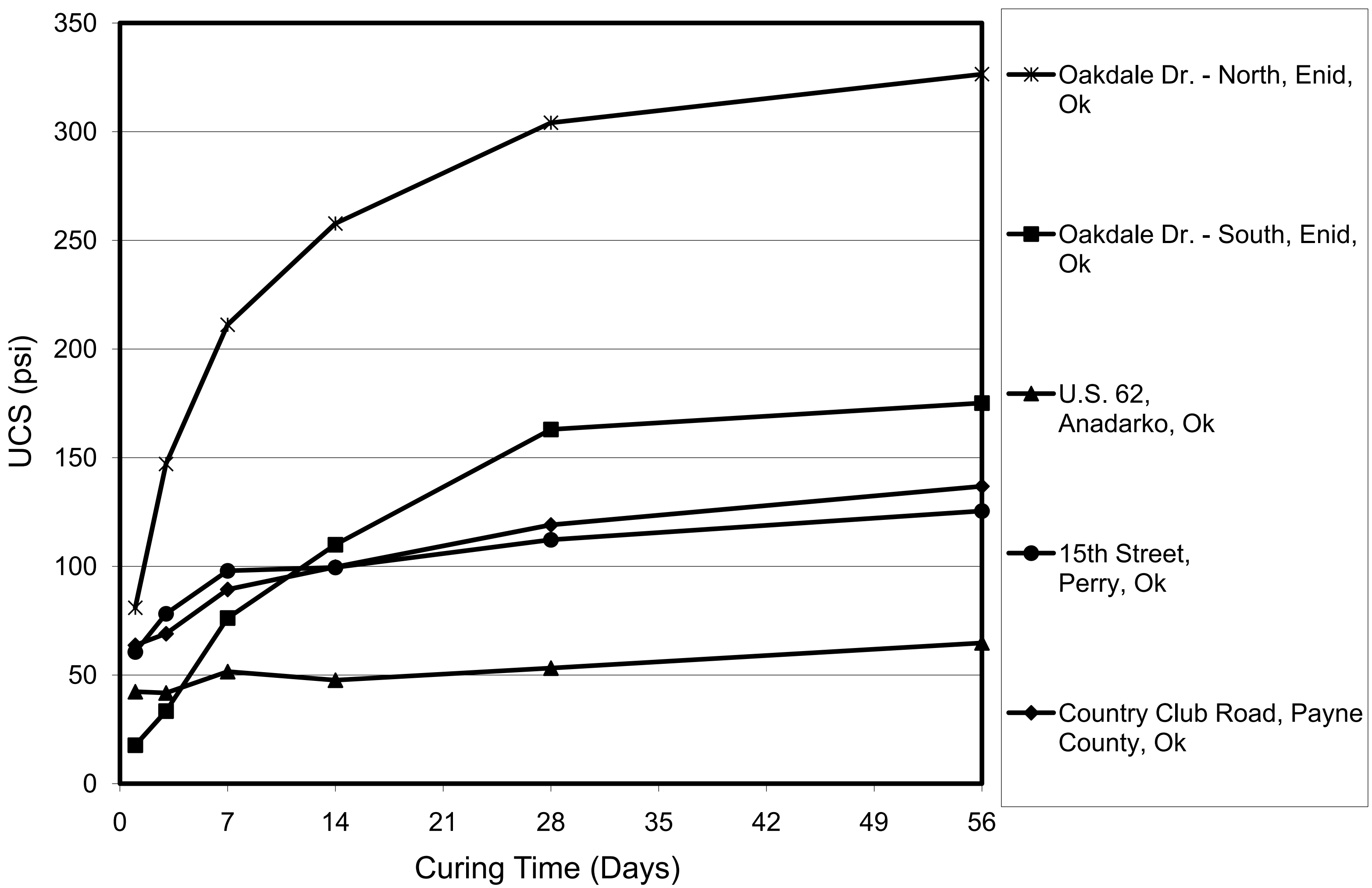


Figure 5.1b
Unconfined Compression Strength versus Curing Time for
Laboratory Mixed Samples



Obviously, the quality of the CKD used on the Oakdale Dr. sites was of very good. Fly ash stabilized soils exhibited a more gradual development of strength. Table 5.1 summarized the percent increase and rate of increase of UCS for the five field test sites. With the exception of Country Club Road, Payne County, the laboratory mixed UCS values were 1.1 to 1.9 times the field mixed UCS values, which is not surprising, especially given the fact that the higher PI soils (A-6) had higher increases (e.g. 1.8 and 1.9) as compared to the lower PI soils (A-2-4 and A-4) (e.g. 1.1 and 1.2). This reflects the greater difficulty of field mixing additives in higher PI soils. The basic conclusion that can be drawn from this is that field mixed UCS values are consistently lower than laboratory mixed strengths by as much as half for higher PI soils and 80% for lower PI soils. Percent increases of treated UCS over untreated UCS for 7-day cure carried from about 70% to over 900% for field mixed samples and about 200% to over 1200% for laboratory mixed samples. The laboratory to field ratios for percent increase in UCS exhibit the same trends as previously discussed for UCS values. The rate of increase, specifically %/day, exhibits the same trends.

Figures 5.2a and 5.2b show M_R with curing time for all five field tests sites for field mixed and laboratory mixed samples, respectfully. The curves are again typical of all stabilized soils treated with cementitious additives (e.g. CKD and FA), that is, an early development of strength then a more gradual development with some leveling or dropping off. Again, with the exception of field mixed samples from Country Club Road, Payne County, CKD stabilized soils exhibited higher M_R values. Fly ash treated soils exhibited a more gradual development of strength. Table 5.2 summarizes the percent increase and rate of increase of M_R for the five field test sites. With the exception of Country Club Road, Payne County, the laboratory mixed M_R values were 1.6 to 4.4 times the field mixed M_R values for 7 day cure and 1.1 to 7.5 for 28 day cure. Again, this is no surprise, but there was no correlation with soil type as noted with UCS values. Percent increase of treated M_R values over untreated M_R values varied from about 40% to about 500% for field mixed samples (Country Club Road, Payne County not included because of previous discussions) and from about 500% to over 1000% for laboratory mixed samples. It would appear that the M_R test, for all its potential procedural problems when testing stabilized soils, is more sensitive to the influence additives have on soils.

The percent increase and rate of increase of strength development are higher and somewhat more variable than corresponding UCS values.

Figures 5.3a, 5.3b, 5.3c, and 5.3d show stiffness (K), modulus (E_{vd}), dynamic cone index (DCI), and PANDA tip resistance, respectively, with curing time for all five field test sites. No consistent trend for stiffness (K) was evident at any of the field test sites. K increased with time at some sites and decreased with time at others. Conceptually, stiffness and corresponding modulus should reflect strength improvement with reasonable confidence, but for whatever reason the stiffness gauge does not. Portable FWD modulus (E_{vd}) with time does show consistent trends of increasing E_{vd} followed by leveling or dropping off. DCI with time show very consistent trends with DCI decreasing initially then leveling off. The one exception, U.S. 62, can be explained by the fact that the soil at the site selected had a high untreated in situ strength. Probably was not the best site along the roadway to monitor strength improvement. PANDA tip resistance with time also showed consistent trends with tip resistance increasing then leveling or dropping off.

Table 5.1

Summary of Percent Increase and Rate of Increase of UCS of all Field Test Sites

Field Test Site	Soil Class.	UCS, psi			% Increase over Untreated		Rate of Increase (Untreated to 7-day)	
		Untreated	7-day	28-day	7-day	28-day	psi/day	%/day
a. Field Mixed Samples								
Oakdale – North (12% CKD)	A-6(1)	23.3	116.4	127.8	400	448	13.3	57.1
Oakdale – South (12% CKD)	A-2-4	5.9	61.4	88.8	941	1405	7.9	134.4
U.S. 62 (12% FA)	A-4	14.5	46.3	61.7	219	326	4.5	31.3
15th Street (12% FA)	A-6 (16)	30.9	51.9	64.7	68	109	3.0	9.7
Country Club Rd (30% FA)	A-4(2)	27.5	178.4	159.6	549	480	21.6	78.4
b. Laboratory Mixed Samples								
Oakdale – North (14% CKD)	A-6(1)	23.3	211.2	304.1	806	1205	26.8	115.1
Oakdale – South (12% CKD)	A-2-4	5.9	76.2	163.0	1192	2663	10.0	170.3
U.S. 62 (15% FA)	A-4	14.5	51.5	53.2	255	269	5.3	36.4
15th Street (15% FA)	A-6 (16)	30.9	98.0	112.2	217	263	9.6	31.0
Country Club Rd (16% FA)	A-4(2)	27.5	59.4	119.1	225	333	8.8	32.1
c. Laboratory to Field Ratios								
Oakdale – North	A-6(1)	-	1.8	2.4	2.0	2.7	2.0	2.0
Oakdale – South	A-2-4	-	1.2	1.8	1.3	1.9	1.3	1.3
U.S. 62	A-4	-	1.1	0.9	1.2	0.8	0.8	0.8
15th Street	A-6 (16)	-	1.9	1.7	3.2	2.4	3.2	3.2
Country Club Rd	A-4(2)	-	0.5	0.7	0.4	0.7	0.4	0.4

NOTE : $\textit{\% of Increase} = \left(\dfrac{\text{Treated UCS} - \text{Untreated UCS}}{\text{Untreated UCS}}\right)100$

$$\textit{Rate of Increase} = \left(\frac{\text{Treated UCS} - \text{Untreated UCS}}{\text{Curing Time}}\right) \textit{ or } \frac{\text{\% Increase}}{\text{Curing Time}}$$

Figure 5.2a
Resient Modulus (M_R) Curing Time for
Field Mixed Samples

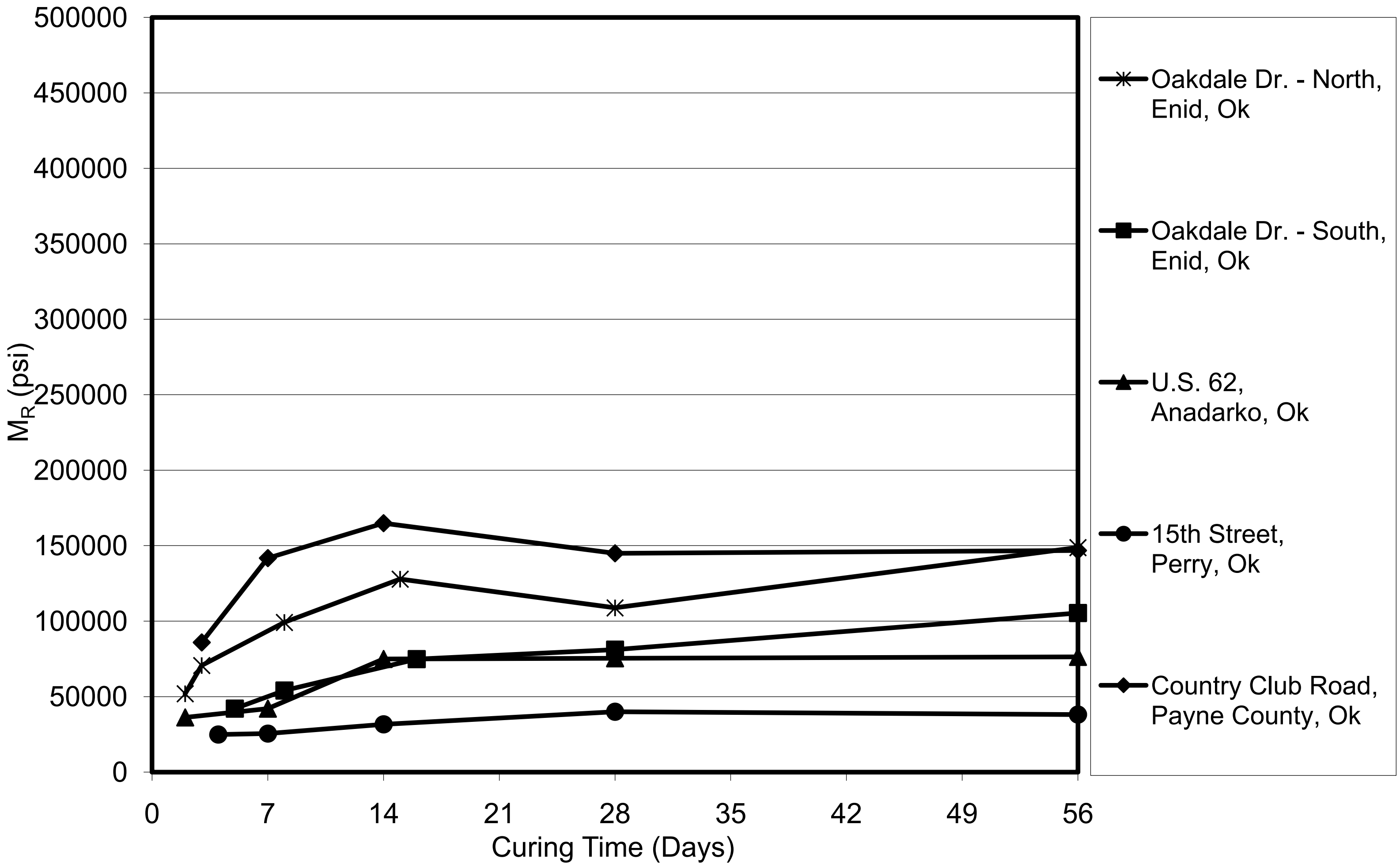


Figure 5.2b
Resient Modulus (M_R) Curing Time for
Laboratory Mixed Samples

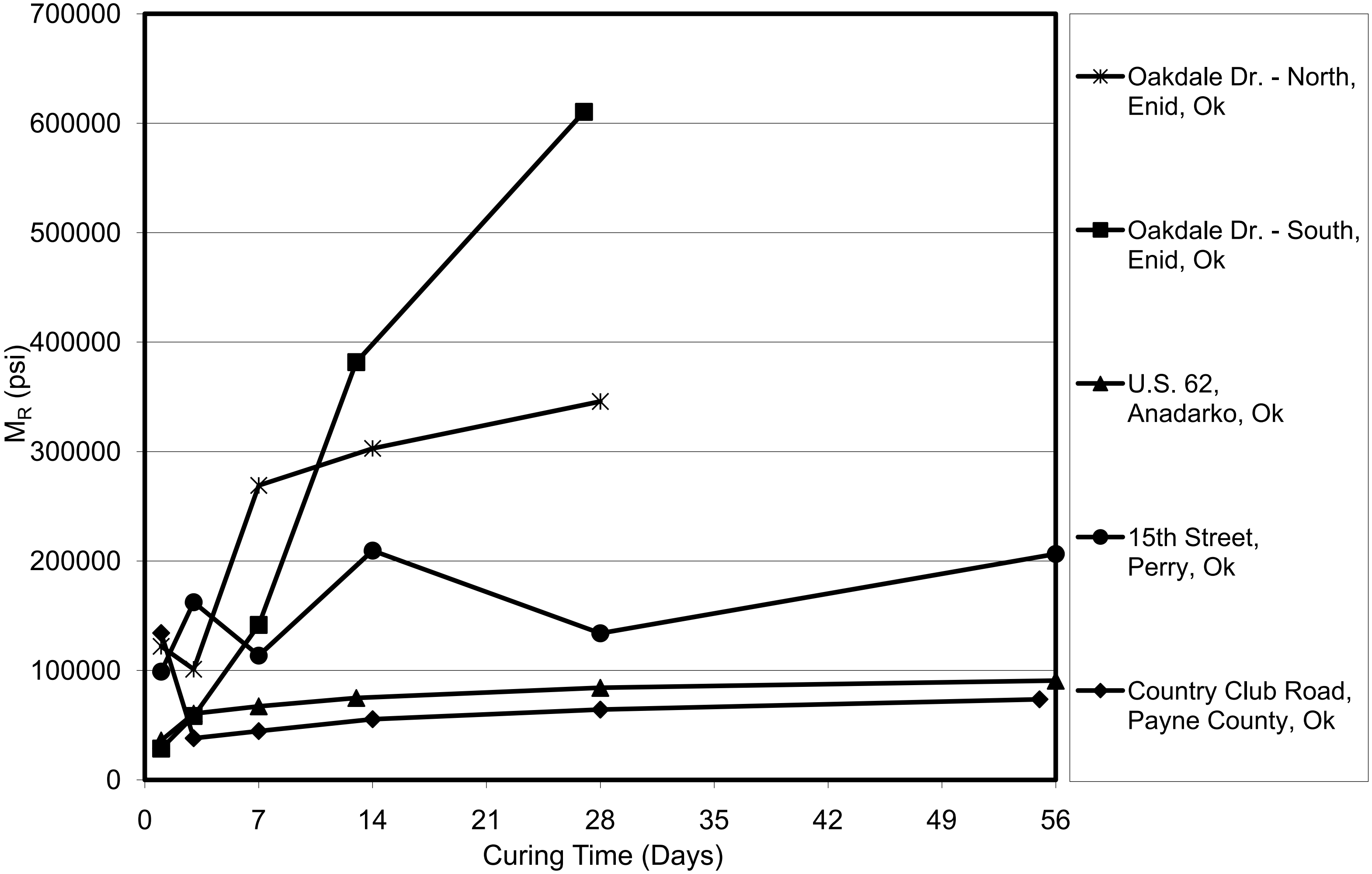


Table 5.2

Summary of Percent Increase and Rate of Increase of M_R for All Field Test Studies

Field Test Site	Soil Class.	M_R, psi			% Increase over Untreated		Rate of Increase (Untreated to 7-day)	
		Untreated	7-day	28-day	7-day	28-day	psi/day	%/Day
a. Field Mixed Samples								
Oakdale – North (12% CKD)	A-6(1)	16642	99175	108837	496	554	11790	70.8
Oakdale – South (12% CKD)	A-2-4	12572	54088	81156	330	546	5931	47.1
U.S. 62 (12% FA)	A-4	12319	42062	75431	241	512	4249	34.4
15th Street (12% FA)	A-6 (16)	17741	25556	40046	44	126	1116	6.3
Country Club Rd (30% FA)	A-4(2)	6314	141765	144929	2145	2195	19350	306.4
b. Laboratory Mixed Samples								
Oakdale – North (14% CKD)	A-6(1)	16642	269011	345272	1516	1975	36053	216.6
Oakdale – South (12% CKD)	A-2-4	12572	141576	610410	1026	4755	18429	146.6
U.S. 62 (15% FA)	A-4	12319	67213	84127	446	583	7842	63.6
15th Street (15% FA)	A-6 (16)	17741	113563	133979	540	655	13689	77.2
Country Club Rd (16% FA)	A-4(2)	6314	44531	64193	605	917	5460	86.5
c. Laboratory to Field Ratios								
Oakdale – North	A-6(1)	-	2.7	3.2	3.1	3.6	3.1	3.1
Oakdale – South	A-2-4	-	2.6	7.5	3.1	8.7	3.1	3.1
U.S. 62	A-4	-	1.6	1.1	1.9	1.1	1.8	1.8
15th Street	A-6 (16)	-	4.4	3.3	12.3	5.2	12.3	12.3
Country Club Rd	A-4(2)	-	0.3	0.4	0.3	0.4	0.3	0.3

$$\textbf{NOTE :}\ \textit{\% of Increase} = \left(\frac{\text{Treated } M_R - \text{ Untreated } M_R}{\text{Untreated } M_R}\right)100$$

$$\textit{Rate of Increase} = \left(\frac{\text{Treated } M_R - \text{Untreated} M_R}{\text{Curing Time}}\right) \ \textit{or} \ \frac{\text{\% Increase}}{\text{Curing Time}}$$

Figure 5.3a
Stiffness Gauge Readings (K)

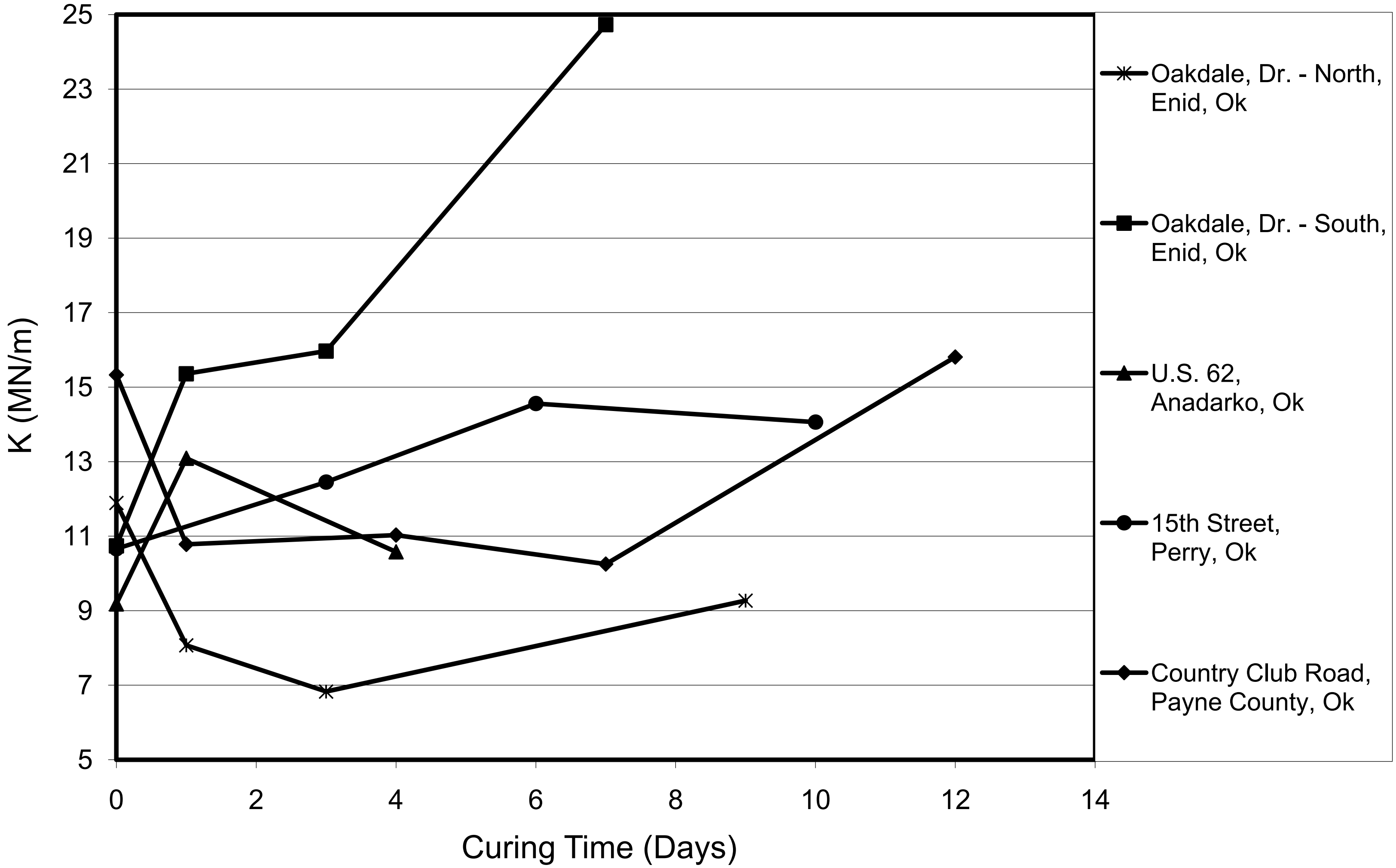


Figure 5.3b
Portable FWD Modulus (E_{vd})

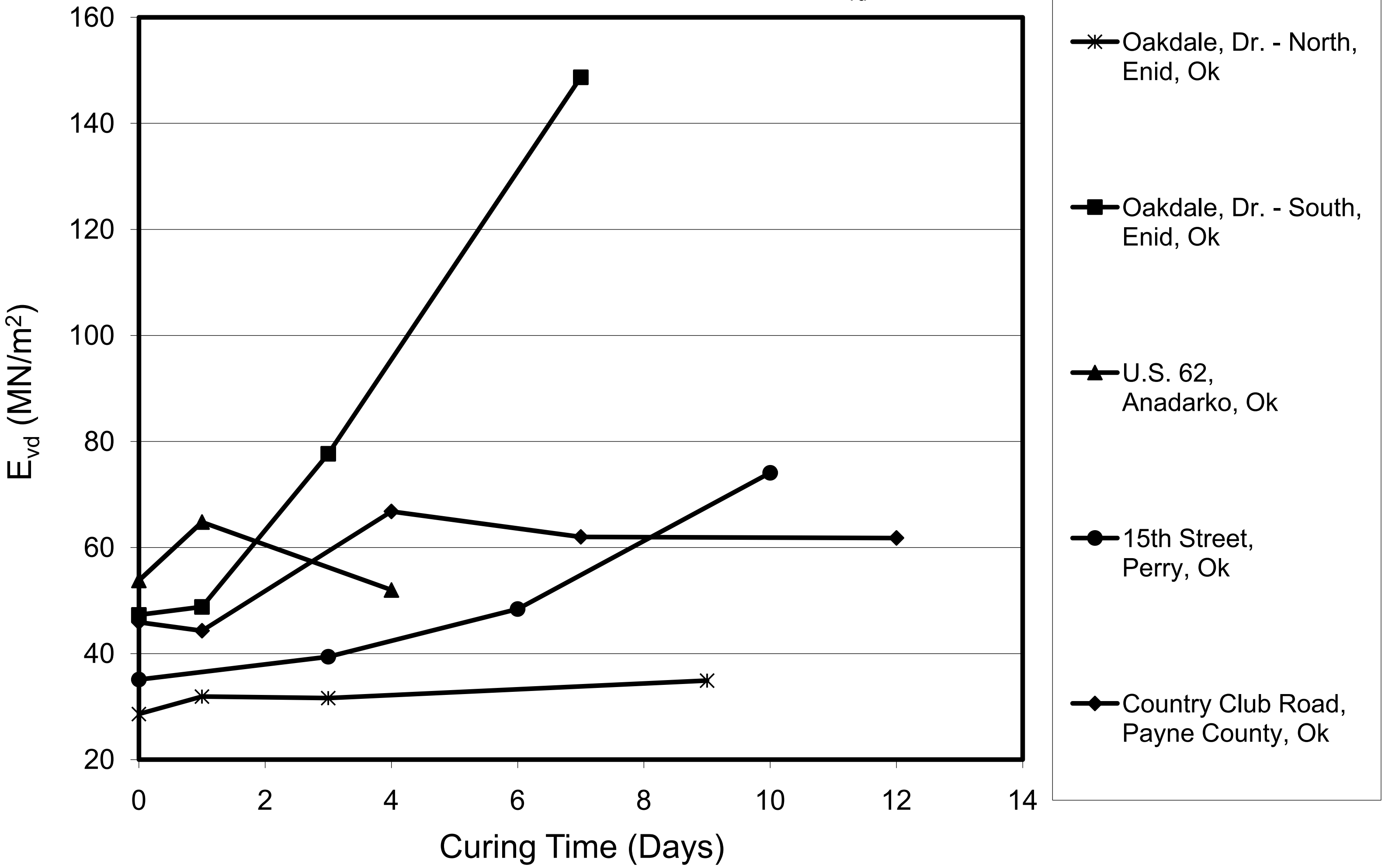


Figure 5.3c
Dynamic Cone Penetration Test - Dynamic Cone Index (DCI)

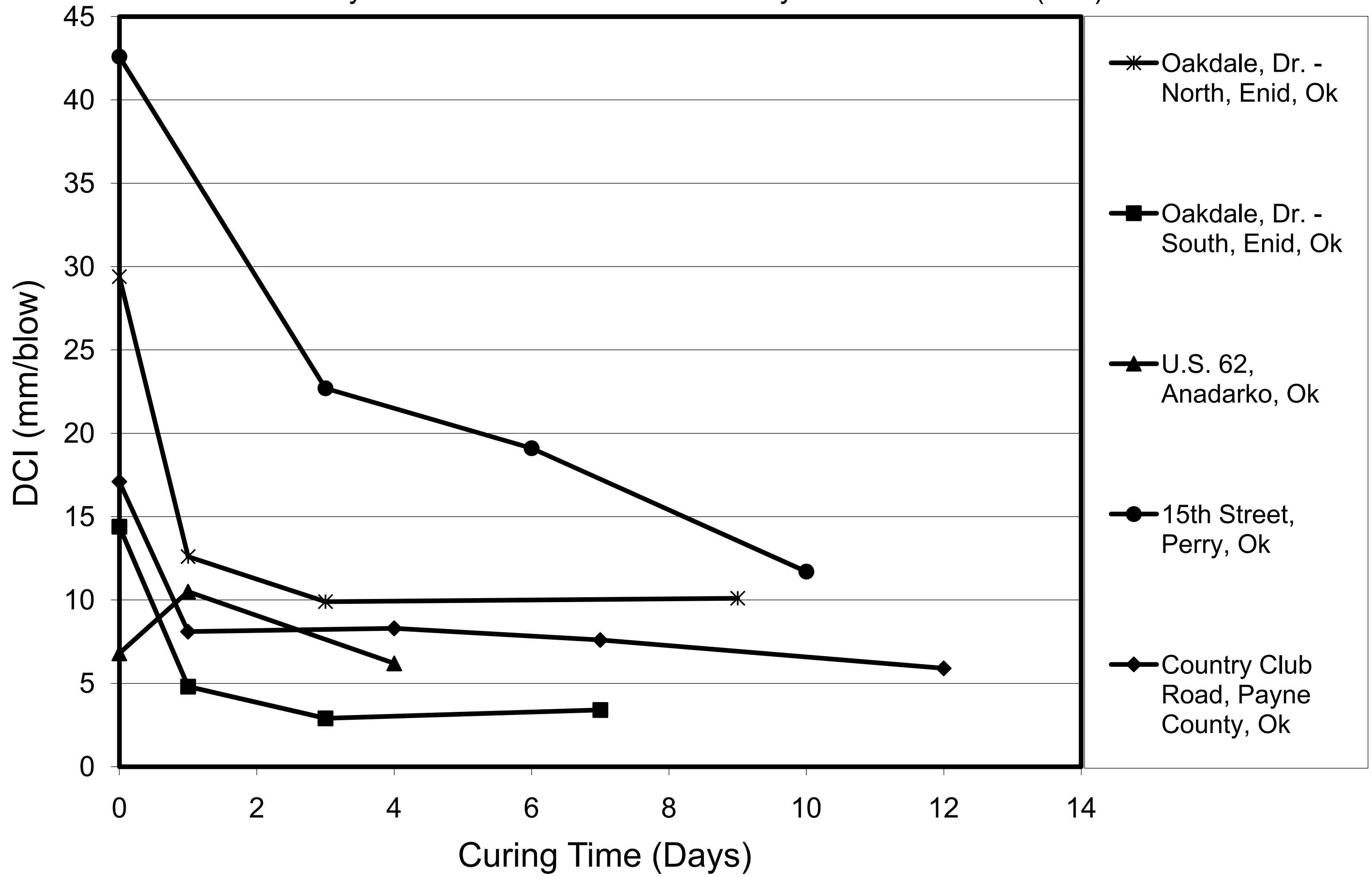
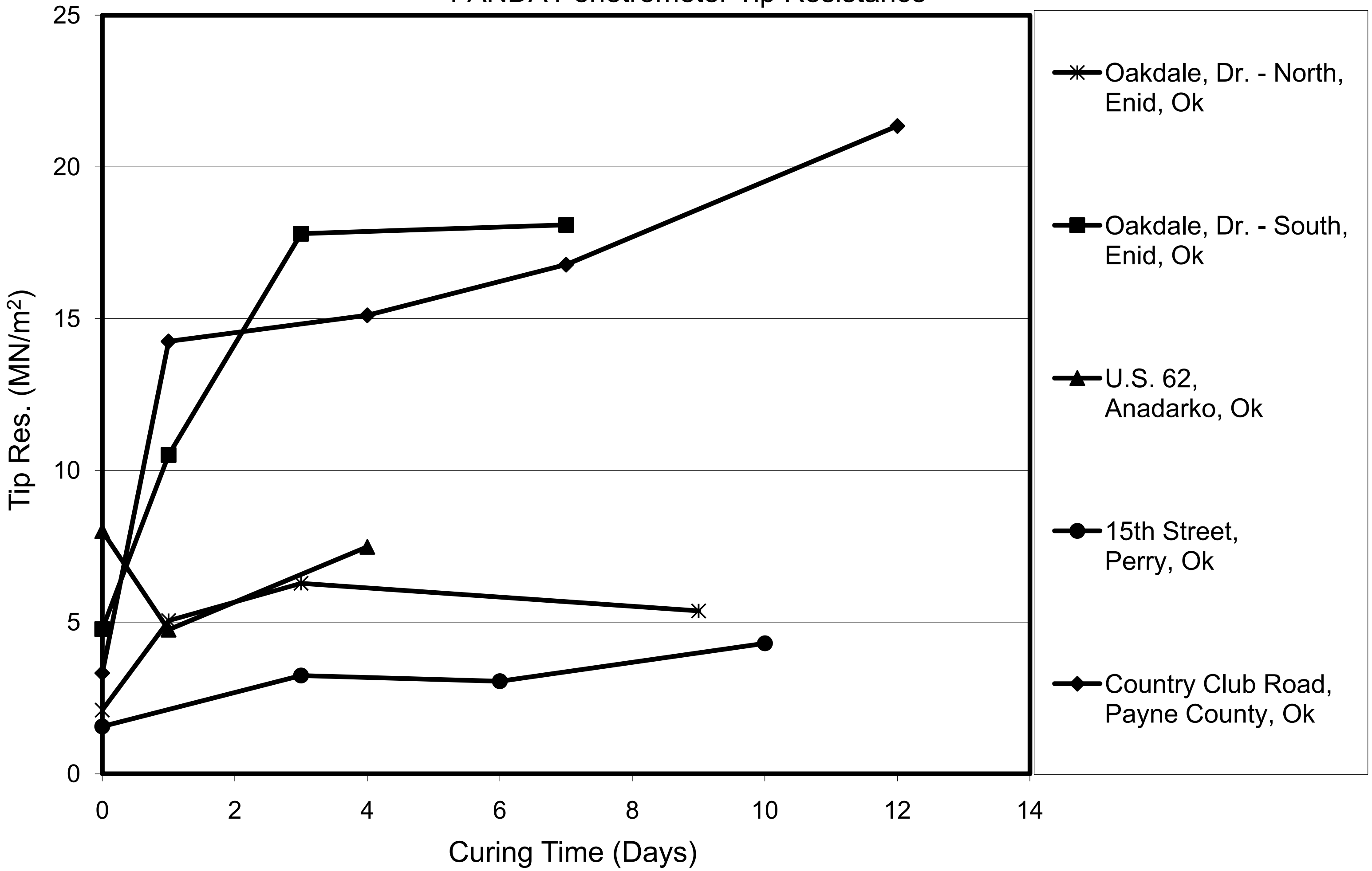


Figure 5.3d
PANDA Penetrometer Tip Resistance



Comparing laboratory test results (UCS or M_R) with field measured parameters (K, E_{vd}, DCI, PTR) is difficult if not impossible. Different qualitative concepts, controlled versus natural environment, and, in some cases, different curing times dictated the measured response . A feasible, although not exact, solution was used involving the percent increase (or decrease as in the case of DCI) and rate of increase. Table 5.3 summarizes percent increase and rate of increase of field data for all field test sites. For stiffness, K, the percent increase and rate of increase showed no correlation with soil type, additive type, or any other observed parameter. Of the remaining field parameters, DCI and PANDA tip resistance (PTR) most closely matched the percent increase and rate of increase trends exhibited by laboratory measured parameters. For examples, DCI and PTR exhibited higher percent increases for CKD stabilized soils and lower values for fly ash stabilized soils. Both DCI and PTR exhibited higher percent increases for non-plastic (A-2-4) and higher PI (A-6) soils, which is reasonable since both soils types should show more improvement. In other words, the poorer the soils the more significant the improvement should be.

Measured M_R and E Values vs. AASHTO-MEPDG 2002 Level 2

Table 2.1 (AASHTO-MEPDG Table 2.2.42) lists several Level 2 correlations for estimating M_R and E values for chemically stabilized soils and unbound gravel and subgrade materials. They are intended to be conservative values that can be used as input parameters in the AASHTO pavement design method in lieu of actual testing (e.g. Level 1). Table 5.4 summarizes measured and calculated M_R and E values using common correlations (e.g. Eq 1) and the correlations from the MEPDG. Comparing measured M_R values with calculated M_R values, it is obvious that the equations are conservative (to extremes in some cases), particularly the MEPDG equations. Given the emphasis on more realistic input parameters in pavement design espoused by AASHTO-MEPDG, the Level 2 correlation equations need “adjusting”. Unfortunately, the relatively small samples size represented in this project makes it difficult to develop new correlation equations, it does suggest some short term alternatives. Specifically, the simple equation M_R = 1500 CBR with CBR values calculated from DCI values measured in stabilized subgrade soil layers would be a good way to approach Level 2 input parameters.

Table 5.3

Summary of Percent Increase and Rate of Increase of Field Data for All Field Test Sites

		Stiffness Gauge				Portable FWD			
Field Test Site	Soil Class.	Untreated K, MN/m, (E, MN/m^2)	Treated K, MN/m, (E, MN/m^2)	% Increase	Rate of Increase % / day	Untreated E_{vd} MN/m^2	Treated E_{vd} MN/m^2	% Increase	Rate of Increase % / day
Oakdale – North (12% CKD) (9 days)	A-6(1)	11.89 (109.95)	9.27 (85.71)	-22.0	-3.1	28.6	34.9	22.0	2.4
Oakdale – South (12% CKD) (7 days)	A-2-4	10.74 (96.44)	24.73 (221.90)	130.3	18.6	47.3	148.7	214.4	30.6
U.S. 62 (12% FA) (4 days)	A-4	9.18 (84.94)	10.58 (97.99)	15.3	2.2	53.8	52.0	-1.8	-0.5
15th Street (12%FA) (6 days)	A-6 (16)	10.66 (100.92)	14.56 (137.92)	36.6	5.2	35.1	48.1	37.0	6.2
Country Club Rd (30%FA) (7 days)	A-4(2)	15.33 (141.78)	10.25 (94.47)	-33.1	-4.7	45.9	62.0	35.1	5.0

		Dynamic Cone Penetration				PANDA Pentrometer			
Field Test Site	Soil Class.	Untreated DCI mm/blow	Treated DCI mm/blow	% Increase	Rate of Increase % / day	Untreated Tip Res MN/m^2	Treated Tip Res MN/m^2	% Increase	Rate of Increase % / day
Oakdale – North (12% CKD) (9 days)	A-6(1)	29.4	10.1	-65.6	-7.3	2.1	5.4	157.1	17.5
Oakdale – South (12% CKD) (7 days)	A-2-4	14.4	3.4	-76.4	-10.9	4.8	18.1	277.1	39.6
U.S. 62 (12% FA) (4 days)	A-4	6.8	6.2	-8.8	-2.2	8.0	7.5	-6.3	-1.6
15th Street (12%FA) (6 days)	A-6 (16)	42.6	19.1	-55.2	-9.3	1.6	3.1	93.8	15.6
Country Club Rd (30%FA) (7 days)	A-4(2)	17.1	7.6	-55.6	-7.9	3.3	16.8	409.1	58.5

Note: Rate of Increase (%/day) based on 7 days curing for all field testing sites.

Table 5.4

Summary of Measured and Calculated M_R and E Values for All Field Test Sites

	Measured				Calculated				
Field Test Site	UCS (Lab Mix, 7-day) psi	E (Initial Tan) (Lab Mix, 7-day) psi	M_R (Lab Mix, 7-day) psi	DCI (field, ≈7-day) mm/blow	M_R (Eq. 1) psi	M_R (Eq. 2) psi	M_R (Eq. 3) psi	M_R (Eq. 4) psi	E (Eq. 5) psi
Oakdale – North (12% CKD) (7 days)	211.2 (23.3)	10454 (1990)	269011 (16642)	10.1 (28.6)	34280	16207	18841	36168	711
Oakdale – South (12% CKD) (7 days)	76.2 (5.9)	8160 (485)	141576 (12572)	3.4 (14.4)	114780	43143	40980	19429	576
U.S. 62 (12% FA) (4 days)	51.5 (14.5)	6498 (1053)	67213 (12319)	6.2 (6.8)	58230	24595	26487	16366	552
15^{th} Street (12%FA) (6 days)	98.0 (30.9)	4520 (2950)	113563 (17741)	19.1 (42.6)	17105	9797	12047	22132	598
Country Club Rd (30%FA) (7 days)	89.4 (27.5)	9140 (1113)	44531 (6314)	7.6 (17.1)	46365	20509	22911	21065	589

Eq. 1 – M_R, psi = 1500 CBR w/ CBR = $292/DCI^{1.12}$

Eq. 2 – M_R, psi = [16.28+(928.4/DCI)]145.2

*Eq. 3 – M_R, psi = $2555(CBR)^{0.64}$ w/ CBR = $292/DCI^{1.12}$

*Eq. 4 – M_R, psi = [0.124 UCS + 9.98]1000

**Eq. 5 – E, psi = 500 + UCS

*AASHTO MEPDG, Chemically Stabilized Soil Group

**AASHTO MEPDG, Unbound Gravel and Subgrade Materials

Note: Numbers ( ) are for untreated soil samples/subgrade.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The following discussion defines and describes the conclusions reached from the research project concerning the verification of strength and structural improvement of stabilized subgrade soils. In addition, several recommendations concerning use of the knowledge obtained from the research as well as future research topics is included.

Conclusions

1. UCS and M_R values for field mixed samples are 50 to 90% of the values for laboratory mixed samples. Generally, the higher the PI of the soil the greater the difference between field and laboratory mixed conditions. This is most likely because more of the cations in the cementitious additives being “used” in cation exchange rather than developing pozzalanic reaction products. Although the research was unable to confirm the differences between field and laboratory mixed conditions the difference could be more or less depending on compaction of the stabilized layer.
2. Measured UCS, M_R, and field parameters such as DCI and PTR indicate that typically 70% or more of the strength and structural improvement occurs in 7 days. The actual rate of improvement is variable and depends on such things as soil type, type, amount, and quality of additive, local construction procedure, and curing environment. The rate of improvement for field mixed and laboratory mixed samples was greater than the rate of improvement of field measured parameters.
3. Cementitious additives such as CKD and FA produce significant increases in strength and structural improvement of stabilized soil layers. For the additives (types and amounts), soils, and construction procedures used in this research project, CKD yielded higher strengths (UCS, M_R) than FA. It’s important to remember that these cementitious additives, particularly CKD, have variable characteristics with regard to potential stabilization applications. Research is currently being conducted to characterize the variability limits.
4. AASHTO-MEPDG Level 2 correlations significantly underestimate M_R and E values for the stabilized soils encountered in this research project. If estimates

of subgrade strength and corresponding structural improvement of the stabilized subgrade are included in pavement design, then either Level 1 (measured) input parameters or alternate Level 2 correlations should be used.

5. The nuclear w-γ gauge is an effective tool for quality control (QC) of compaction of stabilized soil layers.
6. The stiffness gauge K-values and corresponding calculated E-values did not correlate with accepted or measured long term strength and structural improvement of stabilized soil layers.
7. The portable FWD (PFWD) modulus, E_{vd}, is a simple and quick field test that provides a reasonable measure of long term performance of stabilized soil layers. The major problem is the number of factors that can influence modulus/stiffness.
8. The Dynamic Cone Pentrometer (DCP) and Dynamic Cone Index (DCI)and corresponding calculated M_R values provide a good measure of long term performance of stabilized soil layers. The DCI has potential as a performance evaluation tool in QC.
9. The PANDA pentrometer tip resistance (PTR) also provides a good measure of long term performance of stabilized soil layers, probably the best of the equipment used. The PTR also has potential as a performance evaluation in QC as it is currently being used in Europe.

Recommendations

Recommendations are separated as potential for practice and as potential topcs for additional research.

Practice

1. Consider additive percentage such as those given in OHD L-50 to be minimal guidance especially for higher PI soils (A-6, A-7). One potential approach to address the difference between field mixed and laboratory mixed samples would be to increase the percent additive by 3 to 5% or more.
2. Require more chemical variability data on cementitious stabilizers, similar to qualifying aggregate sources.
3. Until better correlations can be established (AASHTO-MEPDG Level 2) use basic correlation of M_R = 1500 CBR with CBR defined from DCI values measured from stabilized soil layers.
4. Do not consider the stiffness gauge as a viable option for QC or long term performance evaluation

Research

1. Evaluate UCS and M_R values for samples taken from field mixed and compacted layers.
2. Evaluate the influence of pre-treatment with lime on the strength improvement of higher PI soils subsequently stabilized with cementitious additives.
3. Evaluate DCI and PTR for different soil types, additive types, and application rates to develop correlation equations for design and QC.

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Appendix 1
Laboratory and Field Data Summaries
for
Oakdale Dr. – North, Enid, Ok

Table A 1.1

Summary of UCS with Curing Time
for Oakdale Dr. - North, Enid, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Field Mixed Samples at 12 % CKD									
Target-->		122.4	14.4	106.7					
1	1	119.1	13.0	105.4	5817.5	0.9	6222.2	56.0	
	2	117.1	11.2	105.3	5255.0	0.9	6472.2	58.3	52.7
	3	116.7	11.5	104.7	1877.5	1.2	3660.8	43.9	
1	1	126.5	21.5	104.0	927.5	1.1	1540.9	17.0	
Soaked	2	127.2	21.6	104.5	1502.5	1.1	1558.2	17.1	17.0
3	1	116.9	12.8	103.6	3307.5	1.1	7688.2	84.6	
	2	116.8	13.0	103.4	1655.0	1.4	5774.3	80.8	79.1
	3	116.3	12.8	103.1	2385.0	1.3	5535.4	72.0	
3 Soaked	1	124.4	22.3	101.7	7215.0	0.7	5735.7	40.2	40.2
7	1	118.6	12.8	105.1	2952.5	1.1	7861.8	86.5	
	2	117.8	11.8	105.4	13307.5	0.8	18856.3	150.9	116.4
	3	116.7	11.7	104.5	12937.5	0.7	15997.1	112.0	
7	1	126.2	20.6	104.6	4990.0	0.7	14738.6	103.2	
Soaked	2	124.2	20.1	103.4	3480.0	0.7	6257.1	43.8	73.5
14	1	117.1	11.7	104.8	16927.5	0.7	18542.9	129.8	
	2	117.8	12.0	105.1	17320.0	0.8	18708.8	149.7	137.8
	3	117.3	11.8	104.9	14535.0	0.9	14885.6	134.0	
14 Soaked	1	123.7	21.3	102.0	14580.0	0.5	13122.0	65.6	65.6

Table A 1.1 (con't)

Summary of UCS with Curing Time
for Oakdale Dr. - North, Enid, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Field Mixed Samples at 12 % CKD									
Target-->		122.4	14.4	106.7					
28	1	118.0	11.7	105.6	26060.0	0.7	19894.3	139.3	
	2	118.2	12.0	105.5	11775.0	1.0	14630.0	146.3	127.8
	3	117.4	12.0	104.5	13390.0	0.7	13994.3	98.0	
28	1	123.3	21.3	101.7	11590.0	0.6	14431.7	86.6	
Soaked	2	124.4	20.0	103.6	9567.5	0.6	9180.0	55.1	70.8

Table A 1.2

Summary of UCS with Curing Time
for Oakdale Dr. - North, Enid, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Laboratory Mixed Samples at 14 % CKD									
Target-->		123.7	10.7	111.7					
1	1	119.9	11.9	107.2	3602.5	1.4	3843.6	53.8	
	2	120.6	11.5	108.2	7645.0	1.2	7890.0	94.7	81.0
	3	120.5	11.3	108.3	7275.0	1.2	7865.8	94.4	
1	1	124.4	20.8	103.0	3707.5	1.4	2603.6	36.5	36.5
Soaked									
3	1	120.9	12.4	107.6	14595.0	1.2	12018.3	144.2	
	2	121.0	12.1	107.9	13707.5	1.2	11591.7	139.1	147.1
	3	119.1	11.4	107.0	5572.5	1.5	10530.0	158.0	
3	1	127.5	19.5	106.8	10650.0	0.9	8922.2	80.3	
Soaked	2	127.3	19.1	106.9	15555.0	0.7	13771.4	96.4	88.4
7	1	120.5	11.7	107.8	13762.5	1.2	19427.5	233.1	
	2	120.1	11.4	107.8	7755.0	1.4	14661.4	205.3	211.2
	3	121.6	12.2	108.3	9845.0	1.4	13940.7	195.2	
7	1	127.1	18.8	107.0	14372.5	0.9	15891.1	143.0	
Soaked	2	127.5	18.4	107.7	8022.5	1.1	11762.7	129.4	136.2
14	1	121.0	11.7	108.3	16325.0	1.1	21109.1	232.2	
	2	120.4	11.2	108.3	15392.5	1.1	23432.7	257.8	257.7
	3	120.5	11.3	108.3	8237.5	1.2	23602.5	283.2	
14	1	126.6	18.0	107.3	17822.5	0.7	20957.1	146.7	
Soaked	2	127.2	17.8	107.9	8880.0	1.0	13671.0	136.7	146.7

Table A 1.2 (con't)

Summary of UCS with Curing Time
for Oakdale Dr. - North, Enid, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
<u>Laboratory Mixed Samples at 14 % CKD</u>									
Target-->		123.7	10.7	111.7					
28	1	122.1	11.5	109.5	6352.5	3.9	8322.8	324.6	
	2	122.1	11.9	109.1	5252.5	3.9	7447.4	290.5	304.1
	3	122.6	12.3	109.1	4095.0	3.9	7622.8	297.3	
28	1	128.6	17.8	109.1	25635.0	0.8	30555.0	244.4	
Soaked	2	128.3	17.7	109.0	31230.0	0.7	34248.6	239.7	242.1
56	1	124.1	11.7	111.1	37855.0	1.0	37722.0	377.2	
	2	124.3	12.1	110.9	15545.0	1.1	28788.2	316.7	326.5
	3	124.7	12.6	110.7	22127.5	1.0	28554.0	285.5	
56	1	129.4	17.8	109.9	43840.0	0.6	44995.0	270.0	
Soaked	2	129.4	17.6	110.0	30540.0	0.7	37068.6	259.5	264.7

Table A 1.3

Summary of UCS with Percent Additive (7-day cure)
for Oakdale Dr. - North, Enid, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
<u>Laboratory Mixed Samples Cured 7-days</u>									
7	1	135.1	13.6	118.9	1870.0	10.1	226.9	22.9	
Untreated	2	136.3	13.6	120.0	2607.5	10.0	256.8	25.7	23.3
	3	136.8	13.7	120.4	1492.5	10.0	212.9	21.3	
7	1	Samples Dissolved							
Untreated	2								
Soaked									
7	1	123.7	12.1	110.4	6625.0	1.3	6473.8	84.2	
6% CKD	2	123.8	12.3	110.2	8970.0	1.2	6660.8	79.9	93.6
	3	123.8	11.5	111.1	12690.0	1.2	9716.7	116.6	
7	1	127.5	16.6	109.3	9927.5	0.8	9705.0	77.6	
6% CKD	2	128.8	16.3	110.7	9830.0	0.6	8538.3	51.2	64.4
Soaked									
7	1	122.4	12.2	109.0	14125.0	1.2	13056.7	156.7	
10% CKD	2	121.9	11.8	109.0	12395.0	1.2	15272.5	183.3	168.9
	3	122.6	11.6	109.9	13652.5	1.1	15165.5	166.8	
7	1	127.7	17.5	108.6	11577.5	0.8	11856.3	94.9	
10% CKD	2	127.9	17.3	109.0	17485.0	0.7	17277.1	120.9	107.9
Soaked									
7	1	116.8	10.1	106.2	15247.5	1.2	18665.0	224.0	
18% CKD	2	117.7	11.5	105.6	9492.5	1.3	15983.8	207.8	218.6
	3	117.6	11.1	105.9	8402.5	1.6	14007.5	224.1	
7	1	124.9	19.5	104.5	10175.0	0.9	17258.9	155.3	
18% CKD	2	125.3	19.4	105.0	5195.0	1.3	9905.4	128.8	142.1

Table A 1.4

Summary of M_R with Curing Time for
Oakdale Dr. - North, Enid, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Field Mixed Samples at 14% CKD									
Target Conditions -->				123.7	10.7	111.7			
2	1	2	9.8				50966		
		4	9.9	--	--	--	51772	51866	51866
		6	9.9				52859		
3	1	2	9.6				36638		
		4	9.7	--	--	--	37617	37465	
		6	9.6				38139		
									70582
4	1	2	12.0				101234		
		4	12.0	119.7	16.9	102.4	103901	103699	
		6	12.0				105962		
8	1	2	12.1				113011		
		4	12.3	124.5	17.2	106.2	116251	11566	
		6	12.3				116536		
									99175
8	2	2	11.6				82864		
		4	11.6	125.0	17.9	106.0	82423	83084	
		6	11.6				83965		
15	1	2	11.8				100123		
		4	11.9	123.6	17.7	105.0	102597	101387	
		6	11.9				101441		
									127849
15	2	2	12.1				156792		
		4	12.1	123.6	17.8	104.9	152955	154311	
		6	12.2				153187		

Table A 1.4 (con't)

Summary of M_R with Curing Time for
Oakdale Dr. - North, Enid, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Field Mixed Samples at 14% CKD									
Target Conditions -->				123.7	10.7	111.7			
28	1	2	11.7				123971		
		4	11.8	124.6	17.8	105.8	124924	123655	
		6	11.8				122074		
									108837
28	2	2	11.6				86748		
		4	11.7	122.2	18.4	103.2	99037	94019	
		6	11.7				96271		
56	1	2	11.9				202177		
		4	12.0	123.9	17.1	105.8	196591	197609	
		6	11.9				194058		
									148787
56	2	2	11.8				98789		
		4	11.8	124.2	18.7	104.6	100406	99964	
		6	11.8				100697		

Table A 1.5

Summary of M_R with Curing Time for
Oakdale Dr. - North, Enid, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples at 14% CKD									
Target Conditions -->				123.7	10.7	111.7			
1	1	2	11.3				94412		
		4	11.2	122.6	9.4	113.1	104005	101491	
		6	11.1				106055		
									121934
1	2	2	11.4				130720		
		4	11.3	124.8	8.4	115.1	148937	142376	
		6	11.0				147470		
3	1	2	11.6				93583		
		4	11.5	119.4	9.8	108.8	100400	99892	
		6	11.4				105694		
									101020
3	2	2	11.7				92390		
		4	11.3	119.3	10.3	108.2	105302	102147	
		6	11.2				108749		
6	1	2	11.4				205298		
		4	11.2	120.0	10.0	109.1	239247	236542	
		6	11.0				264810		
									269011
6	1	2	11.3				294725		
		4	11.1	121.8	10.5	110.2	302236	301570	
		6	10.9				307750		

Table A 1.5 (con't)

Summary of M_R with Curing Time for
Oakdale Dr. - North, Enid, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples at 14% CKD									
Target Conditions -->				123.7	10.7	111.7			
14	1	2	11.5				360856		
		4	11.2	123.3	10.0	112.1	360634	362504	
		6	10.9				366023		
									302828
14	2	2	11.6				229836		
		4	11.4	120.0	10.3	108.8	244719	243152	
		6	11.1				254900		
28	1	2	12.4				329580		
		4	12.1	122.3	10.6	110.6	359855	386221	
		6	11.8				469228		
									345272
28	2	2	12.2				276493		
		4	12.2	121.7	10.1	110.5	288094	304322	
		6	11.8				348380		

Table A 1.6

Summary of M_R with Percent Additive for
Oakdale Dr. - North, Enid, Ok

Curing Time, days and % CKD	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R	
								Spec.	Curing Time
Laboratory Mixed Samples Cured 7 Days									
7	1	2	10.7				16004		
0%		4	10.7	123.0	11.0	110.8	17337	17203	
		6	10.7				18267		
									16642
7	2	2	10.9				15937		
0%		4	10.8	121.4	12.4	108.0	16078	16081	
		6	10.7				16228		
7	1	2	12.5				251647		
6%		4	12.1	--	--	--	252953	252545	
		6	12.2				253035		
									292275
7	2	2	12.6				351163		
6%		4	12.4	--	--	--	324029	332005	
		6	12.1				320824		
7	1	2	12.7				548406		
10%		4	12.4	121.1	12.4	107.7	518135	518290	
		6	12.5				488328		
									484897
7	2	2	12.3				457521		
10%		4	12.1	121.4	10.8	109.6	450663	451503	
		6	12.3				446326		

Table A 1.6 (con't)

Summary of M_R with Percent Additive for
Oakdale Dr. - North, Enid, Ok

Curing Time, days and % CKD	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R	
								Spec.	Curing Time
Laboratory Mixed Samples Cured 7 Days									
7	1	2	11.4				205298		
14%		4	11.2	120.0	10.0	109.1	239247	236252	
		6	11.0				264210		
									268911
7	2	2	11.3				294725		
14%		4	11.1	120.0	10.0	109.1	302236	301570	
		6	10.9				307750		
7	1	2	12.7				684337		
18%		4	12.6	120.1	10.7	108.5	631792	640832	
		6	12.6				606368		
									640832
7	2	2	12.7				2514733		
18%		4	12.5	12.7	10.8	106.9	2963823	--	
		6	12.5				2620111		

Table A 1.7

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - North, Enid, Ok

Date		Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	ν	E MN/m^2
08/16/2007								
	Untreated Subgrade	1	147.0	14.2	128.8	10.26	0.25	94.89
			147.1	14.0	129.1	10.62	0.25	98.22
			147.4	14.5	128.8	10.79	0.25	99.79
		Point Average	147.2	14.2	128.9	10.56	--	97.63
		2	147.8	14.2	129.5	11.47	0.25	106.08
			147.8	14.2	129.5	11.69	0.25	108.11
			147.6	13.9	129.7	11.83	0.25	109.41
		Point Average	147.7	14.1	129.6	11.66	--	107.84
		3	151.2	13.9	132.8	13.08	0.25	120.97
			151.3	12.9	133.9	13.51	0.25	124.95
			151.5	12.7	134.4	13.76	0.25	127.26
		Point Average	151.3	13.2	133.7	13.45	--	124.39
		Site Average	148.7	13.8	130.7	11.89	--	109.95

Table A 1.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - North, Enid, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	ν	E MN/m^2
08/21/2007							
1 - Day Cure	1	131.5	9.7	119.9	6.53	0.25	60.39
		130.9	10.1	118.9	6.72	0.25	62.15
		131.6	9.6	120.0	6.86	0.25	63.44
	Point Average	131.3	9.8	119.6	6.70	--	61.99
	2	135.2	10.6	122.3	8.92	0.25	82.50
		134.8	10.4	122.1	9.39	0.25	86.84
		134.9	10.2	122.5	9.52	0.25	88.05
	Point Average	135.0	10.4	122.3	9.28	--	85.80
	3	134.5	11.1	121.0	7.81	0.25	72.23
		134.5	10.7	121.5	8.29	0.25	76.48
		134.9	11.5	121.1	8.58	0.25	79.35
	Point Average	134.6	11.1	121.2	8.22	--	76.02
	Site Average	133.6	10.4	121.0	8.07	--	74.60

Table A 1.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - North, Enid, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	Nuclear w-γ Gauge w %	Nuclear w-γ Gauge γ_{dry} pcf	Stiffness Gauge K MN/m	Stiffness Gauge ν	Stiffness Gauge E MN/m^2
08/23/2007							
3 - Day Cure (Watered Subgrade prior to Testing)	1	119.3	14.2	104.5	6.04	0.25	55.86
	1	119.9	14.4	104.7	6.34	0.25	58.64
	1	119.4	13.0	104.9	6.34	0.25	58.64
	Point Average	119.5	13.9	104.7	6.24	--	57.71
	2	121.3	15.5	105.1	4.12	0.25	38.10
	2	121.2	15.6	104.9	4.40	0.25	40.69
	2	121.1	15.7	104.7	4.55	0.25	42.08
	Point Average	121.2	15.6	104.9	4.36	--	40.29
	3	126.8	15.3	109.9	9.90	0.25	91.56
	3	127.1	15.0	110.6	9.80	0.25	90.64
	3	127.0	14.9	110.5	10.01	0.25	92.58
	Point Average	127.0	15.1	110.3	9.90	--	91.59
	Site Average	122.6	14.9	106.6	6.83	--	63.20

Table A 1.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - North, Enid, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	ν	E MN/m^2
08/29/2007							
9 - Day Cure (Watered subgrade ~ 1/2 hr prior to testing)	1	121.7	15.5	105.3	5.32	0.25	49.20
		121.7	14.7	106.2	5.54	0.25	51.24
		121.6	15.1	105.6	5.63	0.25	52.07
	Point Average	121.7	15.1	105.7	5.50	--	50.84
	2	123.9	16.3	106.6	11.74	0.25	108.58
		124.1	15.8	107.1	11.96	0.25	110.61
		123.7	15.8	106.8	12.10	0.25	111.91
	Point Average	123.9	16.0	106.8	11.93	--	110.37
	3	123.0	15.1	106.9	10.10	0.25	93.41
		122.9	15.2	106.7	10.36	0.25	95.81
		122.7	15.8	106.0	10.65	0.25	98.50
	Point Average	122.9	15.4	106.5	10.37	--	95.91
	Site Average	122.8	15.5	106.3	9.27	--	85.71

Table A 1.8

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - North, Enid, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
08/16/2007									
Untreated Subgrade	1	21.4	--	--	--	--	--	--	--
		22.1	26.8	7.4	11025	50.98	63.09	75.99	1.96
		22.4	(Upper 0.2m)	--	--	--	--	--	(Upper 0.2m)
	Point Average	22.0							
	2	25.1	--	--	--	--	--	--	--
		26.1	30.5	6.3	9525	46.71	57.45	65.66	2.21
		27.2	(Upper 0.2m)	--	--	--	--	--	(Upper 0.2m)
	Point Average	26.3							
	3	35.3	--	--	--	--	--	--	--
		37.8	30.9	6.3	9390	46.36	56.93	67.73	2.13
		39.2	(Upper 0.2m)	--	--	--	--	--	(Upper 0.2m)
	Point Average	37.4							
	Site Average	28.6	29.4	6.7	9980	48.02	59.16	69.79	2.10

Table A 1.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - North, Enid, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
08/21/2007									
1 - Day Cure		30.5	--	--	--	--	--	--	--
	1	32.1	10.3	21.4	32115	106.40	125.02	221.28	6.33
		34.7	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	32.4							
		27.0	--	--	--	--	--	--	--
	2	28.3	13.9	15.3	23010	76.79	101.03	158.62	5.61
		29.0	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	28.1							
		34.9	--	--	--	--	--	--	--
	3	35.5	13.7	15.6	23385	84.18	102.08	161.20	3.22
		35.4	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	35.3							
	Site Average	31.9	12.6	17.4	26170	89.12	109.38	177.03	5.05

Table A 1.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - North, Enid, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
08/23/2007									
3 - Day Cure (Watered Subgrade prior to Testing)		29.3	--	--	--	--	--	--	--
	1	29.8	6.6	35.4	53055	157.35	172.38	365.73	8.50
		30.2	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	29.8							
		20.0	--	--	--	--	--	--	--
	2	20.9	12.3	17.5	26250	91.56	109.92	180.95	5.13
		21.1	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	20.7							
		45.5	--	--	--	--	--	--	--
	3	44.1	10.8	20.2	30330	101.91	120.56	209.07	5.22
		43.4	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	44.3							
	Site Average	31.6	9.9	24.4	36545	116.87	134.29	251.92	6.28

Table A 1.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - North, Enid, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
08/29/2007									
9 - Day Cure (Watered subgrade ~ 1/2 hr prior to testing)	1	25.3	--	--	--	--	--	--	--
		27.7	7.8	29.4	44040	135.74	153.07	303.58	7.54
		32.7	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	28.6							
	2	29.6	--	--	--	--	--	--	--
		28.8	11.9	18.1	27210	94.02	112.47	187.57	3.76
		28.2	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	28.9							
	3	45.7	--	--	--	--	--	--	--
		47.4	10.5	21.1	31590	105.11	123.47	217.76	4.81
		48.4	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	47.2							
	Site Average	34.9	10.1	22.9	34280	111.62	129.76	236.30	5.37

Appendix 2
Laboratory and Field Data Summaries
for
Oakdale Dr. – South, Enid, Ok

Table A 2.1

Summary of UCS with Curing Time
for Oakdale Dr. - South, Enid, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Field Mixed Samples at 12 % CKD									
Target-->		122.0	10.6	110.3					
1	1	124.9	13.8	109.7	930.0	2.4	668.8	16.1	
	2	124.8	13.6	109.9	1857.5	1.4	1469.3	20.6	18.3
	3	124.8	13.8	109.7	1302.5	1.7	1080.0	18.4	
1 Soaked	1	125.8	17.2	107.3	2032.5	1.1	1468.2	16.2	16.2
3	1	124.7	13.7	109.7	1857.5	1.8	1911.7	34.4	
	2	123.2	13.6	108.5	2935.0	1.5	2998.0	45.0	37.2
	3	124.5	13.3	109.9	2047.5	1.8	1795.0	32.3	
3 Soaked	1	127.4	16.9	109.0	1110.0	1.1	2402.7	26.4	26.4
7	1	123.7	13.3	109.2	2392.5	1.4	4368.6	61.2	
	2	122.9	13.1	108.6	1282.5	1.8	3375.6	60.8	61.4
	3	123.1	13.2	108.7	2200.0	1.7	3662.9	62.3	
7	1	126.0	16.0	108.7	3307.5	1.1	4045.5	44.5	
Soaked	2	125.9	16.0	108.5	5520.0	1.0	3802.0	38.0	41.3
14	1	123.8	13.6	108.9	9370.0	1.3	5152.3	67.0	
	2	123.7	13.2	109.3	4042.5	1.4	5506.4	77.1	68.2
	3	123.8	13.6	109.0	4607.5	1.3	4659.2	60.6	
14	1	126.1	16.3	108.4	8975.0	0.9	6234.4	56.1	
Soaked	2	126.2	16.1	108.7	6980.0	1.0	5040.0	50.4	53.3

Table A 2.1 (con't)

Summary of UCS with Curing Time
for Oakdale Dr. - South, Enid, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Field Mixed Samples at 12 % CKD									
Target-->		122.0	10.6	110.3					
28	1	122.9	13.2	108.6	8555.0	1.2	7520.0	90.2	
	2	125.4	13.9	110.1	7542.5	1.4	7283.6	102.0	88.8
	3	125.0	13.9	109.7	8635.0	1.3	5710.0	74.2	
28	1	126.8	16.7	108.7	6052.5	1.0	4157.0	41.6	
Soaked	2	125.4	16.3	107.8	10822.5	1.0	5470.0	54.7	48.1

Table A 2.2

Summary of UCS with Curing Time
for Oakdale Dr. - South, Enid, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Laboratory Mixed Samples at 12 % CKD									
Target-->		129.9	10.2	117.9					
1	1	127.3	10.1	115.6	1797.5	1.8	944.4	17.0	
	2	125.5	10.0	114.1	1590.0	1.8	937.8	16.9	17.7
	3	127.4	9.9	115.9	2175.0	1.4	1370.0	19.2	
1	1			Samples Dissolved					
Soaked	2								
3	1	126.7	9.9	115.3	1857.5	1.9	1788.9	34.0	
	2	126.5	9.7	115.4	3145.0	1.6	2166.9	34.7	33.4
	3	126.2	9.8	114.9	2850.0	1.7	1848.8	31.4	
3	1	127.5	13.6	112.2	1835.0	1.4	1260.7	17.7	
Soaked	2	128.7	13.6	113.3	3120.0	1.3	1896.2	24.7	21.2
7	1	125.1	10.2	113.6	6730.0	1.4	4437.1	62.1	
	2	126.0	9.6	114.9	6912.5	1.6	5142.5	82.3	76.2
	3	126.2	10.1	114.7	10840.0	1.4	6016.4	84.2	
7	1	128.3	13.3	113.3	11942.5	0.9	6527.8	58.8	
Soaked	2	128.9	13.6	113.5	5005.0	0.9	5822.2	52.4	55.6
14	1	125.8	9.8	114.6	9865.0	1.3	9090.8	118.2	
	2	125.1	9.9	113.9	7312.5	1.4	7572.1	106.0	110.0
	3	125.1	10.3	113.4	10347.5	1.3	8128.5	105.7	
14	1	128.2	12.9	113.5	14345.0	0.9	8152.7	73.4	
Soaked	2	128.9	13.1	114.0	14615.0	0.9	8810.0	79.3	76.3

Table A 2.2 (con't)

Summary of UCS with Curing Time
for Oakdale Dr. - South, Enid, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
<u>Laboratory Mixed Samples at 12 % CKD</u>									
Target-->		129.9	10.2	117.9					
28	1	128.0	9.9	116.5	6967.5	1.4	11082.9	155.2	
	2	127.8	10.1	116.2	16012.5	1.3	12521.5	162.8	163.0
	3	128.3	9.9	116.7	16122.5	1.4	12218.6	171.1	
28	1	131.2	12.8	116.3	14322.5	1.1	10739.1	118.1	
Soaked	2	131.3	12.7	116.5	16920.0	1.0	11875.0	118.8	118.4
56	1	128.1	10.3	116.2	6572.5	1.2	13875.0	166.5	
	2	128.2	10.2	116.3	13695.0	1.2	14840.0	178.1	175.1
	3	128.9	10.2	116.9	5842.5	1.3	13911.5	180.9	
56	1	130.6	13.1	115.4	6937.5	1.1	11529.1	126.8	
Soaked	2	130.4	13.0	115.4	3652.5	1.1	12714.5	139.9	133.3

Table A 2.3

Summary of UCS with Percent Additive
(7-day cure) for Oakdale Dr. - South, Enid, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Laboratory Mixed Samples at cured 7-days									
7	1	128.7	10.0	117.0	475.0	1.4	423.6	5.9	
Untreated	2	128.6	10.1	116.8	480.0	1.4	333.6	4.7	5.9
	3	131.0	10.6	118.5	500.0	1.4	512.1	7.2	
7	1			Both Samples Dissolved					
Untreated	2								
Soaked									
7	1	128.4	9.8	117.0	3615.0	1.3	2947.7	38.3	
6% CKD	2	128.5	8.8	118.1	3122.5	1.4	2601.4	36.4	37.7
	3	129.4	10.0	117.6	3652.5	1.3	2948.5	38.3	
7	1	130.5	11.2	117.3	3105.0	1.2	2473.3	29.7	
6% CKD	2	130.1	11.8	116.4	4547.5	1.1	2524.5	27.8	28.7
Soaked									
7	1	129.0	9.9	117.4	4970.0	1.2	4826.7	57.9	
8% CKD	2	129.3	10.1	117.4	4122.5	1.4	4236.4	59.3	59.3
	3	129.2	10.1	117.4	6390.0	1.2	5052.5	60.6	
7	1	130.1	11.8	116.4	6662.5	1.0	4471.0	44.7	
8% CKD	2	130.1	11.9	116.3	7250.0	0.8	4760.0	38.1	41.4
Soaked									
7	1	125.2	9.9	113.9	3312.5	1.6	3824.4	61.2	
10% CKD	2	125.8	9.4	115.0	9692.5	1.2	5842.5	70.1	66.0
	3	126.3	10.1	114.7	7022.5	1.3	5130.8	66.7	
7	1	128.5	13.1	113.6	6660.0	1.0	4078.0	40.8	
10% CKD	2	128.9	12.4	114.7	7495.0	1.0	4631.0	46.3	43.5
Soaked									

Table A 2.3 (con't)

Summary of UCS with Percent Additive
(7-day cure) for Oakdale Dr. - South, Enid, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
<u>Laboratory Mixed Samples at cured 7-days</u>									
7	1	126.4	9.8	115.2	13502.5	1.4	6492.9	90.9	
16% CKD	2	126.9	9.8	115.6	8817.5	1.7	5640.6	95.9	94.3
	3	126.4	9.9	115.1	6937.5	1.7	5661.8	96.3	
7	1	128.8	14.2	112.7	7387.5	1.0	5671.0	56.7	
16% CKD	2	129.3	14.6	112.8	11345.0	0.9	6805.6	61.3	59.0
Soaked									
7	1	124.7	10.2	113.2	10117.5	1.6	5370.6	85.9	
18% CKD	2	124.6	10.1	113.2	8485.0	1.5	5473.3	82.1	83.4
	3	125.1	10.2	113.5	5040.0	1.7	4830.0	82.1	
7	1	128.9	15.1	112.0	7570.0	1.0	4718.0	47.2	
18% CKD	2	129.5	15.0	112.6	7950.0	1.0	5143.0	51.4	49.3
Soaked									

Table A 2.4

Summary of M_R with Curing Time for
Oakdale Dr. - South, Enid, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Field Mixed Samples at 14% CKD									
Target Conditions-->				129.9	10.2	117.9			
5	1	2	11.3				46364		
		4	11.3	121.5	14.6	106.6	47772	48231	
		6	11.4				50556		
									42098
5	2	2	10.6				35439		
		4	10.6	118.8	15.0	103.3	36491	35965	
		6	--				--		
8	1	2	11.1				67086		
		4	11.3	121.2	14.5	106.1	69514	69161	
		6	11.2				70883		
									54088
8	2	2	10.5				36554		
		4	10.6	119.1	16.1	102.6	39387	39014	
		6	10.7				41100		
16	1	2	11.2				77908		
		4	11.4	119.5	14.7	104.2	81316	69394	
		6	11.3				81892		
									74873
16	2	2	11.1				67105		
		4	11.2	118.0	14.7	102.9	69754	69694	
		6	11.3				71263		

Table A 2.4 (con't)

Summary of M_R with Curing Time for
Oakdale Dr. - South, Enid, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
<u>Field Mixed Samples at 14% CKD</u>									
Target Conditions-->				129.9	10.2	117.9			
28	1	2	11.6				79641		
		4	11.5	119.4	14.7	104.1	82167	81156	
		6	11.4				81661		
									81156
28	2	2	10.5				36153		
		4	10.7	118.3	14.9	103.0	40300	39939	
		6	10.8				43364		
56	1	2	11.3				90024		
		4	11.4	119.0	14.9	103.6	93941	93411	
		6	11.4				96267		
									105449
56	2	2	11.6				114056		
		4	11.6	118.9	14.7	103.7	119264	117487	
		6	11.6				119142		

Table A 2.5

Summary of M_R with Curing Time for
Oakdale Dr. - South, Enid, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples at 14% CKD									
Target Conditions-->				129.9	10.2	117.9			
1	1	2	11.1				21370		
		4	11.2	126.3	10.8	114.0	27309	26511	
		6	11.2				30854		
									28500
1	2	2	11.3				25991		
		4	11.3	129.6	10.7	117.1	31727	30490	
		6	11.3				33751		
3	1	2	11.2				61542		
		4	11.0	127.6	10.6	115.4	63953	63319	
		6	11.0				64461		
									58331
3	2	2	11.4				51104		
		4	11.3	127.0	10.3	115.1	53862	53342	
		6	11.1				55061		
7	1	2	11.3				149854		
		4	11.3	127.0	10.2	115.2	151768	147628	
		6	11.2				141263		
									141576
7	2	2	11.6				--		
		4	11.3	125.5	10.3	113.8	136643	135524	
		6	11.1				134401		

Table A 2.5 (con't)

Summary of M_R with Curing Time for
Oakdale Dr. - South, Enid, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R	
								Spec.	Curing Time
Laboratory Mixed Samples at 14% CKD									
Target Conditions-->				129.9	10.2	117.9			
13	1	2	11.6				321442		
		4	11.6	126.4	10.2	114.7	320703	318757	
		6	11.3				314127		
									381697
13	2	2	11.7				436237		
		4	11.6	125.1	10.1	113.6	444410	444637	
		6	11.5				453265		
27	1	2	12.4				648134		
		4	12.3	125.5	9.6	114.5	476875	534171	
		6	12.0				477505		
									610410
27	2	2	12.3				--		
		4	12.2	126.5	10.1	114.9	--	686649	
		6	11.9				686649		

Table A 2.6

Summary of M_R with Percent Additive for
Oakdale Dr. - South, Enid, Ok

Curing Time, days and % CKD	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples Cured 7 Days									
7	1	2	9.2				9068		
0%		4	11.2	129.4	10.8	116.8	11520	11629	
		6	11.6				14299		
									12572
7	2	2	11.0				11358		
0%		4	11.6	128.1	11.8	114.6	14885	13514	
		6	11.6				14299		
7	1	2	12.1				28302		
4%		4	12.1	127.9	10.5	115.8	33720	33215	
		6	12.1				37622		
									34434
7	2	2	12.1				30911		
4%		4	12.0	128.7	10.4	116.6	36916	35652	
		6	12.0				39130		
7	1	2	12.2				155533		
8%		4	12.2	126.5	10.5	114.5	175495	173685	
		6	12.1				190026		
									133198
7	2	2	12.4				159829		
8%		4	12.3	127.1	10.6	114.9	161633	158711	
		6	12.4				154672		

Table A 2.6 (con't)

Summary of M_R with Percent Additive for
Oakdale Dr. - South, Enid, Ok

Curing Time, days and % CKD	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples Cured 7 Days									
7	1	2	11.3				149845		
12%		4	11.3	127.0	10.2	115.2	151768	147625	
		6	11.2				141263		
									138380
7	2	2	11.6				116362		
12%		4	11.3	125.5	10.3	113.8	136646	129136	
		6	11.1				134401		
7	1	2	12.3				274794		
16%		4	12.4	124.5	10.9	112.3	260470	263123	
		6	12.2				254106		
									233920
7	2	2	12.3				208450		
16%		4	12.3	125.0	10.6	113.0	207954	204717	
		6	12.2				197748		

Table A 2.7

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - South, Enid, Ok

Date		Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	ν	E MN/m^2
08/16/2007	Untreated Subgrade	1	134.5	8.6	123.9	12.42	0.30	111.49
			134.5	8.5	123.9	12.60	0.30	113.11
			134.7	8.3	124.4	12.70	0.30	114.01
		Point Average	134.6	8.5	124.1	12.57	--	112.87
		2	142.4	10.2	129.3	11.91	0.30	106.92
			142.2	10.0	129.3	12.07	0.30	108.35
			142.0	10.1	128.9	12.19	0.30	109.43
		Point Average	142.2	10.1	129.2	12.06	--	108.23
		3	134.0	7.0	125.3	7.58	0.30	68.05
			134.0	6.7	125.6	7.58	0.30	68.05
			133.9	7.0	125.1	7.64	0.30	68.58
		Point Average	134.0	6.9	125.3	7.60	--	68.23
		Site Average	136.9	8.5	126.2	10.74	--	96.44

Table A 2.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - South, Enid, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	ν	E MN/m^2
08/23/2007							
1 - Day Cure	1	127.4	12.9	112.8	15.50	0.30	139.14
		126.9	13.4	111.9	16.10	0.30	144.53
		127.5	14.2	111.7	16.45	0.30	147.67
	Point Average	127.3	13.5	112.1	16.02	--	143.78
	2	130.5	12.5	116.0	16.98	0.30	152.43
		130.6	12.4	116.2	17.11	0.30	153.60
		130.4	13.0	115.4	16.76	0.30	150.45
	Point Average	130.5	12.6	115.9	16.95	--	152.16
	3	132.4	13.2	117.0	12.67	0.30	113.14
		132.1	13.0	116.9	13.16	0.30	118.14
		132.4	13.2	116.9	13.43	0.30	120.56
	Point Average	132.3	13.1	116.9	13.10	--	117.48
	Site Average	130.0	13.1	115.0	15.36	--	137.81

Table A 2.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - South, Enid, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	ν	E MN/m^2
08/25/2007							
3 - Day cure	1	131.1	12.9	116.1	12.36	0.30	110.96
		131.4	13.6	115.7	12.76	0.30	114.55
		131.7	13.0	116.5	12.80	0.30	114.91
	Point Average	131.4	13.2	116.1	12.64	--	113.47
	2	133.5	12.9	118.2	20.24	0.30	181.69
		133.9	12.7	118.8	20.86	0.30	187.26
		133.3	13.0	118.0	21.23	0.30	190.58
	Point Average	133.6	12.9	118.3	20.78	--	186.51
	3	131.5	12.6	116.8	14.24	0.30	127.83
		131.8	12.7	117.0	14.44	0.30	129.63
		131.5	12.7	116.7	14.85	0.30	133.31
	Point Average	131.6	12.7	116.8	14.48	--	130.26
	Site Average	132.2	12.9	117.1	15.97	--	143.41

Table A 2.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - South, Enid, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	ν	E MN/m^2
08/29/2007							
7 - Day Cure	1	124.8	12.4	111.1	35.30	0.30	316.89
		124.9	11.8	111.4	35.01	0.30	314.28
		124.8	11.5	111.7	35.88	0.30	322.09
	Point Average	124.8	11.9	111.6	35.40	--	317.75
	2	128.1	12.0	114.4	24.26	0.30	217.78
		127.3	12.9	112.8	24.34	0.30	218.15
		127.5	12.5	113.3	24.26	0.30	217.78
	Point Average	127.6	12.5	113.5	24.29	--	217.90
	3	125.7	12.6	111.7	14.31	0.30	128.46
		125.7	12.3	111.9	14.56	0.30	130.71
		126.0	12.9	111.6	14.59	0.30	130.97
	Point Average	125.8	12.6	111.8	14.49	--	130.05
	Site Average	126.1	12.3	112.3	24.73	--	221.90

Table A 2.8

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - South, Enid, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
08/16/2007									
Untreated Subgrade	1	45.8	--	--	--	--	--	--	--
		46.8	7.8	29.2	43845	135.79	152.63	302.24	7.37
		47.7	(Upper 02.m)	--	--	--	--	--	--
	Point Average	46.7							
	2	52.8	--	--	--	--	--	--	--
		55.7	12.1	17.8	26760	72.87	111.28	184.47	4.80
		56.3	(Upper 02.m)	--	--	--	--	--	--
	Point Average	54.9							
	3	38.1	--	--	--	--	--	--	--
		40.9	23.4	8.5	12785	55.88	69.34	88.10	2.14
		41.9	(Upper 02.m)	--	--	--	--	--	--
	Point Average	40.3							
	Site Average	47.3	14.4	17.8	27797	94.85	111.08	191.60	4.77

Table A 2.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - South, Enid, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
08/23/2007									
1 - Day Cure		47.6	--	--	--	--	--	--	--
	1	42.0	5.8	41.0	61455	177.15	189.45	423.63	8.60
		34.1	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	41.2							
		42.5	--	--	--	--	--	--	--
	2	48.0	5.2	46.2	69345	195.48	204.67	478.02	9.22
		52.1	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	47.5							
		52.4	--	--	--	--	--	--	--
	3	53.1	3.5	72.2	108270	283.02	272.21	746.34	13.70
		67.4	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	57.6							
	Site Average	48.8	4.8	53.1	79690	218.55	222.11	549.33	10.51

Table A 2.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - South, Enid, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
08/25/2007									
3 - Day Cure	1	74.8	--	--	--	--	--	--	--
		77.1	2.9	89.6	134355	339.71	312.53	926.15	19.10
		82.4	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	78.1							
	2	69.4	--	--	--	--	--	--	--
		78.4	3.3	76.1	114135	295.87	281.55	786.77	16.20
		80.1	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	76.0							
	3	71.7	--	--	--	--	--	--	--
		79.2	2.5	100.0	150000	389.07	335.36	1034.00	18.00
		85.9	--	--	--	--	--	--	--
	Point Average	78.9							
	Site Average	77.7	2.9	88.6	132830	341.55	309.81	915.64	17.80

Table A 2.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Oakdale Dr. - South, Enid, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
08/292007									
7 - Day Cure	1	137.2	--	--	--	--	--	--	--
		136.4	3.0	85.2	127860	325.69	302.78	881.38	20.63
		138.0	--	--	--	--	--	--	--
	Point Average	137.2							
	2	121.6	--	--	--	--	--	--	--
		137.2	3.3	77.9	116895	301.89	285.89	805.80	19.17
		177.2	--	--	--	--	--	--	--
	Point Average	145.3							
	3	153.7	--	--	--	--	--	--	--
		155.2	3.8	66.4	99585	263.81	258.02	686.47	14.47
		178.6	--	--	--	--	--	--	--
	Point Average	163.7							
	Site Average	148.7	3.4	76.5	114780	297.13	282.23	791.22	18.09

Appendix 3
Laboratory and Field Data Summary
for
U.S. 62, Anadarko, Ok

Table A 3.1

Summary of UCS with Curing Time
for U.S. 62, Anadarko, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
<u>Field Mixed Samples at 12 % Fly Ash</u>									
Target-->		126.0	8.6	116.0					
1	1	116.4	8.2	107.6	5175.0	0.9	4330.0	39.0	
	2	116.1	8.5	107.0	3875.0	1.0	4106.0	41.1	40.2
	3	116.2	8.3	107.2	5760.0	0.9	4495.6	40.5	
1	1								
Soaked	2			All Samples Dissolved					
3	1	115.6	7.9	107.1	2952.5	0.9	4324.4	38.9	
	2	115.5	8.0	107.0	7002.5	0.7	5562.9	38.9	41.1
	3	115.7	8.0	107.2	6640.0	0.9	5060.0	45.5	
3	1								
Soaked	2			All Samples Dissolved					
7	1	115.9	7.9	107.4	9905.0	0.6	9023.3	54.1	
	2	116.5	7.8	108.0	6655.0	0.7	6314.3	44.2	46.3
	3	116.2	8.0	107.6	6275.0	0.7	5780.0	40.5	
7	1	125.6	17.6	106.8	7002.5	0.4	7002.5	28.0	
Soaked	2	125.2	18.2	105.9	6460.0	0.4	6460.0	25.8	26.9
14	1	115.8	7.6	107.6	9412.5	0.7	7672.9	53.7	
	2	115.1	8.1	106.5	10722.5	0.7	8592.9	60.2	54.6
	3	116.1	8.0	107.6	10120.0	0.6	8320.0	49.9	
14	1	125.2	17.7	106.3	8032.5	0.4	8032.5	32.1	
Soaked	2	125.8	17.6	107.0	8425.0	0.6	6578.3	39.5	35.8

Table A 3.1 (con't)

Summary of UCS with Curing Time
for U.S. 62, Anadarko, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
<u>Field Mixed Samples at 12 % Fly Ash</u>									
Target-->		126.0	8.6	116.0					
28	1	118.8	8.2	109.7	11645.0	0.7	9682.9	67.8	
	2	117.6	8.0	108.8	12197.5	0.7	8632.9	60.4	61.7
	3	116.5	7.8	108.1	12917.5	0.5	11348.0	56.7	
28	1	125.3	17.6	106.5	9142.5	0.4	9502.5	38.0	
Soaked	2	125.6	17.4	107.0	9312.5	0.4	9312.5	37.3	37.6

Table A 3.2

Summary of UCS with Curing Time
for U.S. 62, Anadarko, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Laboratory Mixed Samples at 15 % Fly Ash									
Target-->		128.8	11.6	115.4					
1	1	126.9	11.8	113.5	4242.5	1.4	2860.7	40.1	
	2	127.4	11.9	113.9	5870.0	1.4	3078.6	43.1	42.3
	3	127.1	11.8	113.7	4832.5	1.4	3133.6	43.9	
1	1	130.0	13.7	114.3	4265.0	0.9	2667.8	24.0	
Soaked	2	129.5	13.9	113.7	2807.5	0.9	3267.8	29.4	26.7
3	1	126.9	11.9	113.3	5625.0	1.3	3355.4	43.6	
	2	127.4	12.0	113.8	4947.5	1.4	2910.7	40.8	41.7
	3	126.7	12.0	113.1	4770.0	1.4	2917.9	40.9	
3	1	128.3	14.1	112.4	3505.0	1.2	2130.0	25.6	
Soaked	2	128.5	13.1	113.6	6990.0	0.9	3807.8	34.3	29.9
7	1	127.6	11.7	114.2	7007.5	1.2	4432.5	53.2	
	2	127.2	11.6	114.0	7282.5	1.1	4853.6	53.4	51.5
	3	127.5	12.2	113.7	5205.0	1.2	4005.0	48.1	
7	1	128.2	13.8	112.7	5552.5	1.1	2767.3	30.4	
Soaked	2	129.7	13.6	114.3	7815.0	0.9	4344.4	39.1	34.8
14	1	128.3	11.9	114.6	4665.0	1.6	2988.8	47.8	
	2	127.8	12.0	114.1	4962.5	1.4	3106.4	43.5	47.6
	3	128.3	11.8	114.7	5180.0	1.8	2861.1	51.5	
14	1	131.4	13.6	115.7	8465.0	0.7	5640.0	39.5	
Soaked	2	130.4	13.7	114.7	8175.0	0.9	4450.0	40.1	39.8

Table A 3.2 (con't)

Summary of UCS with Curing Time
for U.S. 62, Anadarko, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Laboratory Mixed Samples at 15 % Fly Ash									
Target-->		128.8	11.6	115.4					
28	1	129.7	12.2	115.6	7392.5	1.3	3976.2	51.7	
	2	129.9	11.9	116.1	6820.0	1.3	4414.6	57.4	53.2
	3	129.9	12.3	115.7	6025.0	1.4	3605.0	50.5	
28	1	131.2	13.7	115.3	4972.5	1.2	3156.7	37.9	
Soaked	2	131.6	13.6	115.9	5285.0	1.1	4027.3	44.3	41.1
56	1	131.1	11.9	117.2	2580.0	2.0	3299.5	66.0	
	2	132.0	11.9	117.9	4975.0	1.4	4322.9	60.5	64.8
	3	130.2	12.0	116.2	3317.5	1.4	4843.6	67.8	
56	1	131.6	13.0	116.5	9582.5	0.6	8575.0	51.5	
Soaked	2	131.7	13.5	116.0	4097.5	1.6	2483.1	39.7	45.6
Rerun									
7	1	129.7	12.1	115.8	4055.0	1.3	3760.8	48.9	
	2	130.4	12.1	116.3	2210.0	1.6	2956.9	47.3	50.3
	3	130.2	11.9	116.3	3512.5	1.6	3422.5	54.8	
7	1	130.7	14.1	114.6	7382.5	0.7	4938.6	34.6	
Soaked	2	130.3	13.7	114.6	7702.5	0.7	5221.4	36.6	35.6

Table A 3.3

Summary of UCS with Percent Additive
(7-day cure) for U.S. 62, Anadarko, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Laboratory Mixed Samples Cured 7-days									
7	1	129.3	13.9	113.5	940.0	3.2	452.5	14.5	
Untreated	2	128.7	14.0	112.9	1175.0	2.7	508.1	13.7	14.5
	3	128.6	14.0	112.8	1045.0	3.0	511.7	15.4	
7	1	Both Samples Dissolved							
Untreated	2								
Soaked									
7	1	126.5	11.8	113.1	2732.5	1.2	1582.5	19.0	
5% Fly Ash	2	126.5	12.0	112.9	2212.5	1.5	1383.3	20.8	20.7
	3	127.5	12.0	113.8	2237.5	1.6	1390.0	22.2	
7	1	Both Samples Dissolved							
5% Fly Ash	2								
Soaked									
7	1	127.8	12.3	113.8	3502.5	1.3	2330.8	30.3	
10% Fly Ash	2	128.1	12.4	114.0	2917.5	1.7	1920.0	32.6	32.5
	3	128.4	12.3	114.3	3687.5	1.7	2035.3	34.6	
7	1	129.2	14.2	113.2	2417.5	1.1	1644.5	18.1	
10% Fly Ash	2	129.0	14.2	112.9	2957.5	1.1	1648.2	18.1	18.1
Soaked									
7	1	129.0	12.0	115.3	9945.0	1.2	5655.0	67.9	
20% Fly Ash	2	129.4	12.4	115.2	4710.0	1.8	3315.6	59.7	65.3
	3	129.1	12.2	115.1	7540.0	1.4	4885.7	68.4	
7	1	131.4	13.2	116.1	10127.5	0.7	6932.9	48.5	
20% Fly Ash	2	132.1	13.2	116.7	7822.5	0.8	5273.8	42.2	45.4
Soaked									

Table A 3.4

Summary of M_R with Curing Time for
U.S. 62, Anadarko, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Field Mixed Samples at 12% Fly Ash									
Target Conditions-->				128.8	11.6	115.4			
2	1	2	10.0				34114		
		4	10.2	124.6	9.4	113.9	37466	37337	
		6	10.3				40431		
									36239
2	2	2	10.5				33113		
		4	10.8	122.6	8.7	112.8	36003	35140	
		6	10.7				36304		
7	1	2	11.1				38630		
		4	11.2	121.4	9.4	111.0	42327	42115	
		6	11.3				45389		
									42062
7	2	2	10.9				39130		
		4	11.0	122.6	9.1	112.4	42198	42008	
		6	11.1				44695		
14	1	2	11.5				57473		
		4	11.5	121.6	9.0	111.6	62629	64080	
		6	11.5				72138		
									74946
14	2	2	11.8				80270		
		4	11.9	125.2	9.0	114.9	85368	85812	
		6	11.9				91799		

Table A 3.4 (con't)

Summary of M_R with Curing Time for
U.S. 62, Anadarko, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Field Mixed Samples at 12% Fly Ash									
Target Conditions-->				128.8	11.6	115.4			
28	1	2	11.5				81056		
		4	11.6	122.6	9.3	112.2	84960	84430	
		6	11.7				87273		
									75431
28	2	2	11.7				61703		
		4	11.8	123.6	9.0	113.4	67447	66432	
		6	11.8				70146		
56	1	2	11.4				80496		
		4	11.5	122.3	9.3	111.9	85050	85130	
		6	11.5				89843		
									76376
56	2	2	11.4				60755		
		4	11.5	123.2	9.6	112.4	67071	67622	
		6	11.6				75041		

Table A 3.5

Summary of M_R with Curing Time for
U.S. 62, Anadarko, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples at 15% Fly Ash									
Target Conditions-->				128.8	11.6	115.4			
1	1	2	12.1				33455		
		4	11.9	128.1	12.7	113.7	36366	35996	35996
		6	11.9				38168		
3	1	2	11.7				58770		
		4	11.5	128.5	13.2	113.5	62937	61830	
		6	11.4				63784		
									60560
3	2	2	11.9				55878		
		4	11.7	127.6	12.2	113.7	59678	59289	
		6	11.6				62310		
7	1	2	11.8				60339		
		4	11.7	127.3	12.3	113.4	63289	63048	
		6	11.7				65517		
									67213
7	2	2	11.9				68801		
		4	11.8	127.6	12.6	113.3	73425	71379	
		6	11.7				71912		
13	1	2	11.9				67041		
		4	11.8	128.3	12.8	113.7	71353	70237	
		6	11.9				72317		
									74828
13	2	2	12.2				75777		
		4	12.0	128.0	12.5	113.8	79713	79418	
		6	11.9				82765		

Table A 3.5 (con't)

Summary of M_R with Curing Time for
U.S. 62, Anadarko, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
<u>Laboratory Mixed Samples at 15% Fly Ash</u>									
Target Conditions-->				128.8	11.6	115.4			
28	1	2	12.3				85487		
		4	12.2	127.6	12.7	113.2	86863	87688	
		6	12.1				90713		
									84127
28	2	2	12.4				77308		
		4	12.3	128.0	13.1	113.2	81191	80566	
		6	12.2				83198		
56	1	2	11.9				83192		
		4	11.7	129.3	12.3	115.1	98576	90654	90654
		6	11.6				90195		

Table A 3.6

Summary of M_R with Percent Additive for
U.S. 62, Anadarko, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples Cured 7 Days									
7	1	2	10.5				8722		
0%		4	10.6	127.9	11.4	114.8	9687	9786	
		6	10.7				10949		
									12319
7	2	2	10.7				9772		
0%		4	10.9	128.2	11.4	115.1	13472	14851	
		6	11.0				21310		
7	1	2	11.9				16538		
5%		4	12.0	--	--	--	19857	19751	
		6	11.9				22858		
									19474
7	2	2	11.8				16162		
5%		4	11.9	--	--	--	19150	19197	
		6	11.9				22279		
7	1	2	--				--		
10%		4	12.0	126.9	12.4	112.9	31278	32475	
		6	12.0				33672		
									31801
7	2	2	12.2				27513		
10%		4	12.2	126.7	13.3	111.8	30987	31126	
		6	12.1				34879		

Table A 3.6 (con't)

Summary of M_R with Percent Additive for
U.S. 62, Anadarko, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R	
								Spec.	Curing Time
Laboratory Mixed Samples Cured 7 Days									
7	1	2	11.8				60339		
15%		4	11.7	127.3	12.3	113.4	63289	63048	
		6	11.7				65517		
									67214
7	2	2	11.9				68801		
15%		4	11.8	127.6	12.6	113.3	73425	71379	
		6	11.7				71912		
7	1	2	12.5				94360		
20%		4	12.5	129.3	12.3	115.1	99612	98798	
		6	12.4				102421		
									101869
7	2	2	12.2				105860		
20%		4	12.3	126.6	12.3	112.7	103165	104940	
		6	12.3				105795		

Table A 3.7

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
U.S. 62, Anadarko, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	ν	E MN/m^2
07/30/2007							
Untreated Subgrade	1	126.6	6.5	118.8	11.38	0.25	105.25
		126.8	6.5	119.1	11.41	0.25	105.52
		126.8	6.6	119.0	11.56	0.25	106.91
	Point Average	126.7	6.5	119.0	11.45	--	105.89
	2	127.3	7.8	118.1	8.40	0.25	77.69
		128.1	8.0	118.6	8.66	0.25	80.09
		126.8	8.0	117.4	8.89	0.25	82.22
	Point Average	127.4	7.9	118.0	8.65	--	80.00
	3	121.7	6.5	114.2	7.27	0.25	67.24
		122.1	6.9	114.3	7.56	0.25	69.92
		121.9	6.3	114.7	7.53	0.25	69.64
	Point Average	122.9	6.6	114.4	7.45	--	68.93
	Site Average	126.7	7.0	117.1	9.18	--	84.94

Table A 3.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
U.S. 62, Anadarko, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	ν	E MN/m^2
08/28/2007							
1 - Day Cure	1	125.0	6.6	117.3	11.02	0.25	101.92
		124.8	6.4	117.3	11.02	0.25	101.92
		124.7	6.4	117.2	10.90	0.25	100.81
	Point Average	124.8	6.5	117.3	10.97	--	101.55
	2	121.6	6.6	114.1	12.18	0.25	112.64
		121.5	6.3	114.3	12.30	0.25	113.75
		121.2	6.6	113.7	12.44	0.25	115.05
	Point Average	121.4	6.5	114.0	12.31	--	113.81
	3	124.8	7.1	116.6	15.79	0.25	146.03
		124.7	6.7	116.9	15.96	0.25	147.60
		124.6	7.4	116.1	16.20	0.25	149.82
	Point Average	124.7	7.1	116.5	15.98	--	147.82
	Site Average	123.6	6.7	115.9	13.09	--	121.06

Table A 3.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
U.S. 62, Anadarko, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	ν	E MN/m^2
08/31/2007							
4 - Day Cure	1	122.1	5.7	115.4	8.54	0.25	78.98
		122.0	5.7	115.4	8.70	0.25	80.46
		122.1	5.8	115.3	8.82	0.25	81.57
	Point Average	122.1	5.7	115.4	8.69	--	80.34
	2	119.3	5.7	112.9	11.20	0.25	103.58
		119.1	5.6	112.8	11.20	0.25	103.58
		119.3	6.2	112.4	11.35	0.25	104.97
	Point Average	119.2	5.8	112.7	11.25	--	104.04
	3	120.6	6.2	113.6	11.73	0.25	108.48
		120.8	6.1	113.9	11.82	0.25	109.31
		120.5	5.9	113.8	11.88	0.25	109.87
	Point Average	120.6	6.1	113.8	11.81	--	109.22
	Site Average	120.6	5.9	114.0	10.58	--	97.99

Table A 3.8

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
U.S. 62, Anadarko, Ok

	Date	Test Point	Portable FWD E_{vd} MN/m^2	DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
				Dynamic Cone Penetration Test (DCP)						
Untreated Subgrade	07/30/2007									
		1	51.3	--	--	--	--	--	--	--
			46.7	5.4	44.4	66600	189.14	199.45	459.10	10.11
			17.8	(Upper 0.15m)	--	--	--	--	--	--
		Point Average	18.6							
		2	62.2	--	--	--	--	--	--	--
			67.6	7.5	30.5	45810	140.05	156.97	315.78	7.36
			62.8	(Upper 0.15m)	--	--	--	--	--	--
		Point Average	64.2							
		3	46.7	--	--	--	--	--	--	--
			49.6	7.4	31.0	46515	141.72	158.52	320.64	6.48
			49.9	(Upper 0.15m)	--	--	--	--	--	--
		Point Average	48.7							
		Site Average	53.8	6.8	35.3	52975	156.97	171.65	365.17	8.00

Table A 3.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
U.S. 62, Anadarko, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
08/28/2007									
1 - Day Cure	1	63.4	--	--	--	--	--	--	--
		65.2	10.6	20.6	30975	103.52	122.20	213.05	4.26
		65.4	(Upper 0.15m)	--	--	--	--	--	--
	Point Average	64.7							
	2	63.9	--	--	--	--	--	--	--
		66.4	12.7	17.0	25470	89.54	107.81	175.57	3.51
		67.6	(Upper 0.15m)	--	--	--	--	--	--
	Point Average	67.0							
	3	62.2	--	--	--	--	--	--	--
		63.9	8.1	28.2	42330	131.59	149.23	291.79	6.47
		62.0	(Upper 0.15m)	--	--	--	--	--	--
	Point Average	62.7							
	Site Average	64.8	10.5	21.9	32925	108.22	126.08	226.96	4.75

Table A 3.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
U.S. 62, Anadarko, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
08/31/2007									
4 - Day Cure		59.2	--	--	--	--	--	--	--
	1	60.0	5.2	46.0	69045	194.79	204.11	475.95	9.24
		59.5	(Upper 0.15m)	--	--	--	--	--	--
	Point Average	59.6							
		47.3	--	--	--	--	--	--	--
	2	44.3	7.6	30.3	45480	139.23	156.25	313.51	6.52
		45.9	(Upper 0.15m)	--	--	--	--	--	--
	Point Average	45.8							
		50.3	--	--	--	--	--	--	--
	3	50.8	5.9	40.1	60165	174.14	186.89	414.74	6.68
		--	(Upper 0.15m)	--	--	--	--	--	--
	Point Average	50.6							
	Site Average	52.0	6.2	38.8	58230	169.39	182.42	401.40	7.48

Appendix 4
Laboratory and Field Data Summaries
for
15th Street, Perry, Ok

Table A 4.1

Summary of UCS with Curing Time
for 15th Street, Perry, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Field Mixed Samples at 12 % Fly Ash									
Target-->		125.6	14.1	110.1					
1	1	128.3	14.9	111.6	3137.5	2.1	1795.2	37.7	
	2	127.9	14.5	111.7	3690.0	1.4	2555.7	35.8	38.3
	3	128.1	14.2	112.2	2587.5	1.8	2307.8	41.5	
1	1	130.1	17.2	111.0	2755.0	1.1	1990.0	21.9	
Soaked	2	128.5	17.3	109.5	4055.0	0.7	3254.3	22.8	22.3
3	1	129.5	14.7	112.9	2957.5	2.0	2182.5	43.7	
	2	128.8	14.6	112.4	4805.0	1.8	2591.1	46.6	45.6
	3	128.9	14.4	112.6	1292.5	1.8	2587.2	46.6	
3	1	131.3	16.6	112.6	5737.5	0.7	4321.4	30.3	
Soaked	2	130.5	16.6	111.9	6817.5	0.7	4511.4	31.6	30.9
7	1	129.3	14.9	112.6	2215.0	1.8	2587.2	46.6	
	2	129.1	14.5	112.8	4975.0	1.4	4010.7	56.2	51.9
	3	129.4	14.3	113.2	1290.0	1.8	2946.7	53.0	
7	1	131.1	16.3	112.7	5537.5	0.7	5148.6	36.0	
Soaked	2	131.1	16.5	112.5	6672.5	0.7	4922.9	34.5	35.3
14	1	129.5	14.7	112.9	4040.0	1.8	3062.8	55.1	
	2	129.7	15.2	112.5	4245.0	1.8	3112.8	56.0	56.2
	3	129.3	14.7	112.7	5152.5	1.4	4108.6	57.5	
14	1	131.3	16.0	113.2	4224.3	0.7	5892.9	41.3	
Soaked	2	131.1	16.1	112.9	6275.0	1.1	3398.2	37.4	39.3

Table A 4.1 (con't)

Summary of UCS with Curing Time
for 15th Street, Perry, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
<u>Field Mixed Samples at 12 % Fly Ash</u>									
Target-->		125.6	14.1	110.1					
28	1	130.1	14.8	113.3	2400.0	1.4	4225.0	59.2	
	2	130.1	14.5	113.6	6285.0	1.4	4702.1	65.8	64.7
	3	130.2	14.5	113.7	7542.5	1.4	4942.1	69.2	
28	1	131.5	16.0	113.4	5335.0	1.4	3484.3	48.8	
Soaked	2	131.2	15.8	113.3	1285.0	2.4	1736.1	41.7	45.2

Table A 4.2

Summary of UCS with Curing Time
for 15th Street, Perry, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Laboratory Mixed Samples at 15 % Fly Ash									
Target-->		122.9	15.4	106.5					
1	1	121.9	17.3	104.0	4010.0	1.6	3899.4	62.4	
	2	122.3	17.7	104.0	4772.5	1.2	4337.5	52.1	60.6
	3	122.5	17.2	104.5	2665.0	1.6	4210.0	67.4	
1	1	Both Samples Dissolved							
Soaked	2								
3	1	123.5	17.6	105.1	8710.0	1.3	5433.8	70.6	
	2	123.5	17.0	105.6	8032.5	1.4	6037.1	84.5	78.2
	3	123.7	17.3	105.4	10322.5	1.2	6610.8	79.3	
3 Soaked	1	126.8	19.9	105.8	2837.5	0.8	2916.3	23.3	23.3
7	1	124.5	16.9	106.5	4827.5	2.5	4020.0	100.5	
	2	124.5	16.9	106.5	3997.5	2.4	3972.5	95.3	98.0
	3	124.8	16.9	106.8	4735.0	2.4	4083.8	98.0	
7	1	125.7	19.7	105.0	9367.5	0.5	9476.0	47.4	
Soaked	2	125.6	21.0	103.8	3467.5	0.7	5378.6	37.7	42.5
14	1	125.6	16.8	107.5	7687.5	1.2	7784.2	93.4	
	2	125.5	17.1	107.2	10425.0	1.1	5978.0	105.6	99.5
	3	125.5	16.9	107.3	4842.5	1.5	9595.5	89.7	
14	1	127.4	19.6	106.5	10220.0	0.9	7802.2	70.2	
Soaked	2	128.3	20.0	107.0	11045.0	0.6	9831.7	59.0	64.6

Table A 4.2 (con't)

Summary of UCS with Curing Time
for 15th Street, Perry, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Laboratory Mixed Samples at 15 % Fly Ash									
Target-->		122.9	15.4	106.5					
28	1	126.0	17.2	107.5	9055.0	1.1	10338.2	113.7	
	2	126.0	17.2	107.5	8317.5	1.1	10141.8	111.6	112.2
	3	125.9	17.7	107.0	5352.5	1.1	10119.1	111.3	
28	1	127.4	19.5	106.7	2032.5	1.6	3786.9	60.6	
Soaked	2	128.3	19.8	107.1	9125.0	0.7	11558.6	80.9	70.8
56	1	125.8	16.4	108.1	3317.5	1.4	8957.9	125.4	
	2	125.7	17.6	106.9	4620.0	1.3	8899.2	115.7	125.5
	3	125.7	16.7	107.7	2772.5	1.4	9665.0	135.3	
56	1	126.7	19.2	106.3	15455.0	0.7	13828.6	96.8	
Soaked	2	126.7	20.1	105.4	15407.5	0.5	16992.0	85.0	90.9

Table A 4.3

Summary of UCS with Percent Additive
(7-day cure) for 15th Street, Perry, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Laboratory Mixed Samples Cured 7-Days									
7	1	127.7	20.0	106.5	2952.5	7.8	375.1	29.3	
Untreated	2	128.4	19.8	107.2	3522.5	10.0	303.6	30.4	30.9
	3	128.4	19.5	107.5	2375.0	7.5	439.2	32.9	
7	1								
Untreated	2				Both Samples Dissolved				
Soaked									
7	1	127.7	17.3	108.9	8502.5	1.4	5562.1	77.9	
5% Fly Ash	2	127.9	17.6	108.8	3622.5	1.9	4062.6	77.2	74.6
	3	127.7	17.9	108.4	8150.0	1.4	4908.6	68.7	
7	1	129.6	20.8	107.3	2160.0	0.8	2067.5	16.5	
5% Fly Ash	2	127.5	20.6	105.7	1882.5	1.0	1261.0	12.6	14.6
Soaked									
7	1	125.9	17.7	107.0	2860.0	1.8	4115.0	74.1	
7.5% Fly Ash	2	125.1	17.6	106.4	5465.0	1.4	5500.7	77.0	74.0
	3	125.6	17.9	106.6	5952.5	1.4	5062.9	70.9	
7	1	127.0	19.9	105.9	4750.0	0.7	5270.0	36.9	
7.5% Fly Ash	2	128.1	19.8	106.9	5100.0	0.9	4861.1	43.8	40.3
Soaked									
7	1	125.1	17.0	106.9	5105.0	1.1	7224.5	79.5	
10% Fly Ash	2	125.4	17.1	107.1	2470.0	1.4	4630.0	64.8	76.6
	3	125.2	17.3	106.7	8592.5	1.1	7764.5	85.4	
7	1	128.2	20.1	106.7	4975.0	0.9	4631.1	41.7	
10% Fly Ash	2	130.0	19.5	108.9	5307.5	0.9	5657.8	50.9	46.3
Soaked									

Table A 4.3 (con't)

Summary of UCS with Percent Additive
(7-day cure) for 15th Street, Perry, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Laboratory Mixed Samples Cured 7-Days									
7	1	126.4	17.8	107.3	4655.0	1.6	5272.5	84.4	
12.5% Fly Ash	2	126.3	17.0	108.0	4460.0	1.4	6307.1	88.3	88.6
	3	126.0	17.2	107.5	7050.0	1.4	6662.1	93.3	
7	1	129.5	19.0	108.8	6912.5	0.7	6745.7	47.2	
12.5% Fly Ash	2	128.5	19.3	107.7	3732.5	1.0	3909.0	39.1	43.2
Soaked									
7	1	124.0	16.3	106.7	11297.5	1.2	9828.3	117.9	
20% Fly Ash	2	125.3	16.8	107.3	5455.0	1.4	7369.3	103.2	104.2
	3	125.5	17.6	106.7	5575.0	1.6	5709.4	91.4	
7	1	127.1	19.7	106.2	15432.5	0.5	13174.0	65.9	
20% Fly Ash	2	127.4	19.5	106.6	12512.5	0.6	11360.0	68.2	67.0
Soaked									

Table A 4.4

Summary of M_R with Curing Time for
15th Street, Perry, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Field Mixed Samples at 12% Fly Ash									
Target Conditions-->				122.9	15.4	106.5			
4	1	2	9.8				26099		
		4	10.0	123.1	15.2	106.9	28269	28073	
		6	10.1				29850		
									24939
4	2	2	9.4				20099		
		4	9.6	122.4	16.1	105.4	21896	21804	
		6	9.7				23417		
7	1	2	9.6				23501		
		4	9.9	123.3	15.9	106.6	25142	25731	
		6	10.1				28550		
									25566
7	2	2	9.8				23276		
		4	9.9	121.4	15.7	104.9	25470	25401	
		6	9.9				27456		
14	1	2	9.9				29270		
		4	10.2	125.3	15.3	108.7	32479	32045	
		6	10.2				34385		
									31713
14	2	2	10.3				28476		
		4	10.4	124.4	16.3	107.0	31698	31381	
		6	10.4				33970		

Table A 4.4 (con't)

Summary of M_R with Curing Time for
15th Street, Perry, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Field Mixed Samples at 12% Fly Ash									
Target Conditions-->				122.9	15.4	106.5			
28	1	2	10.6				35211		
		4	10.7	127.5	15.7	110.2	38341	37905	
		6	10.8				40162		
									40046
28	2	2	10.6				39583		
		4	10.8	126.0	16.8	107.9	42390	42187	
		6	10.8				44589		
56	1	2	10.9				30724		
		4	10.9	123.4	15.9	106.5	34267	34385	
		6	11.0				38164		
									38133
56	2	2	11.1				39841		
		4	11.1	125.1	16.4	107.5	42055	41880	
		6	11.1				43745		

Table A 4.5

Summary of M_R with Curing Time for
15th Street, Perry, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples at 15% Fly Ash									
Target Conditions-->				122.9	15.4	106.5			
1	1	2	12.5				99174		
		4	12.2	123.9	16.2	106.6	96030	96701	
		6	12.1				94898		
									98905
		2	12.1				102181		
1	2	4	12.0	124.0	16.0	106.9	100891	101108	
		6	12.1				100252		
		2	12.1				134832		
3	1	4	12.1	122.5	16.2	105.4	136444	136288	
		6	12.1				137587		
									162276
		2	12.2				190753		
3	2	4	12.0	123.0	15.5	106.5	185715	188264	
		6	12.0				188325		
		2	12.3				145777		
7	1	4	12.2	120.9	15.7	104.5	138077	139869	
		6	12.2				135754		
									113563
		2	12.2				83371		
7	2	4	12.0	119.8	16.8	102.6	88015	87257	
		6	11.9				90386		

Table A 4.5 (con't)

Summary of M_R with Curing Time for
15th Street, Perry, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples at 15% Fly Ash									
Target Conditions-->				122.9	15.4	106.5			
		2	12.5				195374		
14	1	4	12.4	120.2	15.8	103.8	191585	194228	
		6	12.3				195725		
									209475
		2	12.6				210579		
14	2	4	12.4	121.4	15.5	105.1	204587	224721	
		6	12.3				258996		
28	1	2	11.6				157388		
		4	11.5	119.1	15.1	103.5	149945	152664	
		6	11.4				150659		
									133979
28	2	2	11.9				111130		
		4	11.5	122.2	15.8	105.5	115603	115294	
		6	11.3				119149		
56	1	2	12.0				204604		
		4	11.7	122.8	15.5	106.3	206469	204993	
		6	11.6				203905		
									206384
56	2	2	11.7				213042		
		4	11.4	119.1	16.0	102.7	209632	207774	
		6	11.4				201648		

Table A 4.6

Summary of M_R with Percent Additive for
15th Street, Perry, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples Cured 7 Days									
7	1	2	10.9				17400		
0%		4	10.9	121.8	16.6	104.5	17783	17741	
		6	10.9				18040		
									17741
7	2	2	--				--		
0%		4	11.2	125.9	17.7	107.0	39013	39065	
		6	11.2				39116		
7	1	2	12.4				108721		
5%		4	12.2	122.6	15.4	106.2	113251	111672	
		6	12.3				113043		
									109300
7	2	2	12.3				106568		
5%		4	12.3	121.9	16.8	104.4	106957	106928	
		6	12.3				107258		
7	1	2	12.4				239997		
10%		4	12.1	122.4	15.8	105.7	240226	245224	
		6	12.2				255449		
									222165
7	2	2	12.1				175432		
10%		4	11.9	122.1	15.6	105.6	209689	199102	
		6	11.9				212198		

Table A 4.6 (con't)

Summary of M_R with Percent Additive for
15th Street, Perry, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples Cured 7 Days									
7	1	2	12.3				145777		
15%		4	12.2	120.9	15.7	104.5	138007	139846	
		6	12.2				135754		
									113552
7	2	2	12.2				83371		
15%		4	12.0	119.8	16.8	102.6	88015	87257	
		6	11.9				90386		
7	1	2	12.3				199837		
20%		4	12.2	122.2	15.6	105.7	199046	199740	
		6	12.1				200338		
									199740
7	2	2	12.3				583361		
20%		4	12.1	121.9	16.1	105.0	657888		
		6	12.1				589585		

Table A 4.7

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
15th Street, Perry, Ok

		Nuclear w-γ Gauge			Stiffness Gauge		
Date	Test Point	γ_{moist} pcf	w %	γ_{dry} pcf	K MN/m	υ	E MN/m^2
07/26/2007							
Untreated Subgrade	1	126.2	22.5	103.0	11.77	0.20	111.46
		126.0	23.5	102.0	11.92	0.20	112.89
		--	--	--	12.00	0.20	113.64
	Point Average	126.1	23.0	102.5	11.90	--	112.66
	2	126.5	21.4	104.2	11.66	0.20	110.42
		126.5	21.9	103.8	11.89	0.20	112.60
		--	--	--	11.99	0.20	113.55
	Point Average	126.5	21.7	104.0	11.85	--	112.19
	3	126.7	21.0	104.7	8.16	0.20	77.28
		126.8	21.3	104.5	8.35	0.20	79.09
		--	--	--	8.17	0.20	77.37
	Point Average	126.8	21.2	104.6	8.23	--	77.91
	Site Average	126.5	22.0	103.7	10.66	--	100.92

Table A 4.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
15th Street, Perry, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	υ	E MN/m^2
09/09/2007							
3 - Day Cure	1	129.5	14.9	112.7	12.87	0.20	121.88
		129.1	14.9	112.3	13.57	0.20	128.51
		129.5	15.0	112.6	13.93	0.20	131.92
	Point Average	129.4	14.9	112.6	13.46	--	127.44
	2	124.5	13.6	109.5	6.74	0.20	63.83
		124.9	13.9	109.6	6.81	0.20	64.49
		124.8	14.1	109.4	6.89	0.20	65.25
	Point Average	124.7	13.9	109.5	6.81	--	64.52
	3	128.0	13.0	113.2	17.04	0.20	161.37
		127.8	12.3	113.8	17.32	0.20	164.03
		128.3	13.0	113.6	16.87	0.20	159.79
	Point Average	1280.0	12.8	113.5	17.08	--	161.72
	Site Average	127.4	13.9	111.9	12.45	--	117.89

Table A 4.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
15th Street, Perry, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	υ	E MN/m^2
09/12/2007							
6 - Day Cure	1	125.5	12.1	111.9	16.36	0.20	154.93
		125.6	12.1	112.1	16.45	0.20	155.79
		124.9	11.6	112.0	16.39	0.20	155.79
	Point Average	125.3	11.9	112.0	16.40	--	155.31
	2	127.4	11.9	113.9	10.53	0.20	99.72
		127.3	12.8	112.8	10.56	0.20	100.01
		127.3	12.8	112.9	10.60	0.20	100.39
	Point Average	127.3	12.5	113.2	10.56	--	100.04
	3	131.0	11.7	117.3	16.42	0.20	155.50
		131.4	12.6	116.7	16.79	0.20	159.00
		131.2	12.5	116.7	16.97	0.20	160.71
	Point Average	131.2	12.3	116.9	16.72	--	158.40
	Site Average	127.9	12.2	114.0	14.56	--	137.92

Table A 4.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
15th Street, Perry, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	υ	E MN/m^2
09/16/2007							
10 - Day Cure	1	126.3	9.7	115.1	12.71	0.20	120.37
		126.0	10.5	114.0	12.94	0.20	122.55
		126.2	9.6	115.1	13.10	0.20	124.06
	Point Average	126.2	9.9	114.7	12.92	--	122.33
	2	125.6	8.9	115.4	10.08	0.20	95.46
		125.3	9.1	114.9	10.20	0.20	96.60
		125.5	9.1	115.0	10.29	0.20	97.45
	Point Average	125.5	9.0	115.1	10.19	--	96.50
	3	127.4	9.7	116.2	19.16	0.20	181.45
		127.7	9.5	116.7	19.20	0.20	181.83
		127.2	9.5	116.2	18.86	0.20	178.61
	Point Average	127.4	9.6	116.4	19.07	--	10.63
	Site Average	126.4	9.5	115.4	14.06	--	133.15

Table A 4.8

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
15th Street, Perry, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
07/26/2007									
Untreated Subgrade		29.5	--	--	--	--	--	--	--
	1	28.9	52.8	34.0	5160	33.88	38.81	35.57	1.18
		31.2	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	29.9							
		61.5	--	--	--	--	--	--	--
	2	62.8	27.9	7.0	10530	49.60	61.26	72.59	2.23
		--	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	62.2							
		12.9	--	--	--	--	--	--	--
	3	13.3	47.0	3.9	5865	36.03	42.12	40.43	1.28
		--	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	13.1							
	Site Average	35.1	42.6	4.8	7185	39.84	47.40	49.53	1.56

Table A 4.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
15th Street, Perry, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
09/09/2007									
3 - Day Cure		52.7	--	--	--	--	--	--	--
	1	47.7	25.9	7.6	11445	51.15	64.61	78.89	2.91
		57.8	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	52.7							
		15.2	--	--	--	--	--	--	--
	2	15.9	27.6	7.1	10665	49.95	61.76	73.52	2.74
		17.6	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	6.2							
		48.3	--	--	--	--	--	--	--
	3	50.1	14.6	14.5	21780	79.99	97.54	150.14	4.07
		49.7	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	49.4							
	Site Average	39.4	22.7	9.7	14630	60.70	74.64	100.85	3.24

Table A 4.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
15th Street, Perry, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
			Dynamic Cone Penetration Test (DCP)						
09/12/2007									
6 - Day Cure		28.3	--	--	--	--	--	--	--
	1	28.0	18.8	10.9	16350	65.60	81.18	112.71	2.81
		27.4	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	27.9							
		38.8	--	--	--	--	--	--	--
	2	39.1	24.3	8.2	12315	54.56	67.72	84.89	2.29
		36.9	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	38.3							
		73.8	--	--	--	--	--	--	--
	3	78.9	14.1	15.1	22650	82.25	100.01	156.13	4.04
		81.2	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	78.0							
	Site Average	48.1	19.1	11.4	17105	67.47	82.97	117.91	3.05

Table A 4.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research
Field Data Summary

Project Location:
15th Street, Perry, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
			Dynamic Cone Penetration Test (DCP)						
09/16/2007									
10 - Day Cure		53.6	--	--	--	--	--	--	--
	1	61.6	13.7	15.5	23280	83.89	101.78	160.48	4.30
		62.3	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	59.2							
		71.7	--	--	--	--	--	--	--
	2	68.2	12.9	16.6	24870	88.01	106.18	171.44	**
		69.2	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	69.7							
		94.1	--	--	--	--	--	--	--
	3	93.4	8.5	26.7	400035	126.00	144.00	275.97	**
		93.0	(Upper 0.2m)	--	--	--	--	--	--
	Point Average	93.5							
	Site Average	74.1	11.7	19.6	29395	99.30	117.32	202.63	4.30

** Panda Penetrometer Malfunction

Appendix 5
Laboratory and Field Data Summaries
for
Country Club Road, Payne County, Ok

Table A 5.1

Summary of UCS with Curing Time
for Country Club Road, Payne County, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Field Mixed Samples at 30% Fly Ash									
Target-->		128.8	12.4	114.6					
1	1	125.6	11.4	112.8	6440.0	1.2	11157.5	133.9	
	2	124.9	11.6	111.9	6755.0	1.1	10486.4	115.4	112.3
	3	123.2	11.7	110.3	8420.0	1.1	7964.5	87.6	
1	1	129.0	16.0	111.1	9880.0	1.0	8727.0	87.3	
Soaked	2	129.8	15.8	112.1	10720.0	1.0	10806.0	108.1	97.7
3	1	125.6	11.6	112.6	3000.0	1.3	12065.4	156.9	
	2	124.9	11.7	111.8	16592.5	1.0	14754.0	147.5	146.3
	3	125.6	12.2	111.9	16742.5	0.9	14935.6	134.4	
3	1	130.1	16.0	112.1	12272.5	0.9	15406.7	138.7	
Soaked	2	129.9	16.0	112.0	16325.0	0.9	13376.7	120.4	129.5
7	1	125.4	12.2	111.8	7595.0	1.1	15622.7	171.9	
	2	125.3	11.7	112.1	5952.5	1.2	16052.5	192.6	178.4
	3	125.9	12.7	111.7	9097.5	1.1	15517.3	170.7	
7	1	130.1	15.5	112.6	17082.5	0.8	14021.3	112.2	
Soaked	2	130.0	15.0	113.0	15280.0	0.9	17188.9	154.7	133.4
14	1	126.4	12.4	112.4	14912.5	1.1	14820.0	163.0	
	2	127.0	12.0	113.4	11037.5	1.2	17257.5	207.1	183.2
	3	127.5	12.0	113.8	13325.0	1.1	16324.5	179.6	
14 Soaked	1	129.7	14.3	113.5	13080.0	0.9	17080.0	153.7	153.7

Table A 5.1 (con't)

Summary of UCS with Curing Time
for Country Club Road, Payne County, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Field Mixed Samples at 30% Fly Ash									
Target-->		128.8	12.4	114.6					
28	1	127.9	13.7	112.4	7617.5	1.9	5248.9	99.73	
	2	127.8	13.2	112.9	5115.0	1.6	10056.3	160.9	159.6
	3	128.4	12.1	114.6	6782.5	1.3	16779.2	218.1	
28	1	130.6	15.0	113.6	14855.0	0.9	17825.6	160.4	
Soaked	2	130.4	15.0	113.4	6802.5	1.0	12238.0	122.4	141.4

Table A 5.2

Summary of UCS with Curing Time
for Country Club Road, Payne County, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Laboratory Mixed Samples at 16 % Fly Ash									
Target-->		132.6	11.9	118.5					
1	1	131.5	12.3	117.1	3747.5	2.7	2169.3	58.6	
	2	132.2	12.3	117.7	4410.0	2.7	2222.2	60.0	63.7
	3	131.8	12.1	117.6	4777.5	2.7	2687.8	72.6	
1	1	132.3	15.1	115.0	3035.0	1.2	2321.7	27.9	
Soaked	2	132.6	14.8	115.5	3492.5	1.2	2561.7	30.7	29.3
3	1	131.7	13.1	116.5	6852.5	1.6	3791.9	60.7	
	2	131.8	12.8	116.8	7630.0	1.6	4111.9	65.8	69.0
	3	131.4	12.4	116.9	7793.6	1.8	4473.3	80.5	
3	1	135.1	14.0	118.5	6247.5	1.1	4510.9	49.6	
Soaked	2	135.3	14.4	118.3	7877.5	1.0	4434.0	44.3	47.0
7	1	132.8	12.8	117.7	8355.0	1.6	4800.6	76.8	
	2	133.0	12.1	117.6	7977.5	1.5	6346.7	95.2	89.4
	3	133.8	11.9	119.5	11090.0	1.4	6866.4	96.1	
7	1	134.9	14.1	118.3	8057.5	1.0	5140.0	51.4	
Soaked	2	134.6	14.6	117.4	8115.0	0.9	4953.3	44.6	48.0
14	1	133.0	12.4	118.3	3242.5	1.8	5531.7	99.6	
	2	133.7	12.4	119.0	7282.5	1.7	5817.1	98.9	99.7
	3	133.6	12.5	118.8	5322.5	2.0	5026.5	100.5	
14	1	134.9	13.9	118.5	6320.0	0.9	6593.3	59.3	
Soaked	2	134.7	13.8	118.4	3455.0	1.4	4187.9	58.6	59.0

Table A 5.2 (con't)

Summary of UCS with Curing Time
for Country Club Road, Payne County, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
<u>Laboratory Mixed Samples at 16 % Fly Ash</u>									
Target-->		132.6	11.9	118.5					
28	1	133.1	12.0	118.8	8280.0	1.2	11061.7	132.7	
	2	133.3	12.3	118.7	7947.5	1.3	8895.4	115.6	119.1
	3	133.1	12.9	117.9	7750.0	1.4	7772.1	108.8	
28	1	134.5	13.5	118.5	16635.0	0.7	11997.1	84.0	
Soaked	2	134.8	14.0	118.3	14047.5	0.7	10632.9	74.4	79.2
56	1	133.3	12.4	118.6	9722.5	1.6	8286.3	132.6	
	2	133.2	12.2	118.7	6052.5	1.3	10340.0	134.4	136.8
	3	133.2	12.1	118.8	11555.0	1.1	13045.5	143.5	
56	1	133.8	14.1	117.3	4217.5	1.0	7579.0	75.8	
Soaked	2	134.2	14.2	117.5	12840.0	0.9	10703.3	96.3	86.1

Table A 5.3

Summary of UCS with Percent Additive
(7-day cure) for Country Club Road, Payne County, Ok

Curing Time, days		Moist Density, pcf	w, %	Dry Density, pcf	E (Initial Tan) psi	Strain @ Failure, %	E (Secant) psi	UCS psi	Average UCS psi
Laboratory Mixed Samples Cured 7-days									
7	1	137.5	13.9	120.8	1100.0	10.0	278.6	27.9	
Untreated	2	137.7	14.2	120.6	970.0	10.0	272.8	27.3	27.5
	3	136.8	13.9	120.1	1267.5	10.0	274.5	27.5	
7	1								
Untreated Soaked	2	Both Samples Dissolved							
7	1	133.7	11.9	119.5	7060.0	1.9	3995.8	75.9	
8% Fly Ash	2	133.7	12.4	118.9	5137.5	2.1	3082.9	64.7	67.6
	3	134.6	12.3	119.9	2070.0	2.6	2390.0	62.1	
7	1	135.3	14.2	118.4	6600.0	0.8	3977.5	31.8	
8% Fly Ash Soaked	2	135.8	14.2	118.9	4842.5	0.7	3594.3	25.2	28.5
7	1	133.8	12.8	118.7	7060.0	1.9	3996.3	75.9	
12% Fly Ash	2	133.8	12.4	119.0	4675.0	2.2	3434.5	75.6	74.6
	3	134.0	12.5	119.1	7282.5	2.0	3619.0	72.4	
7	1	134.9	14.6	117.8	5870.0	1.0	3975.0	39.8	
12% Fly Ash Soaked	2	134.9	14.5	117.8	7115.0	1.2	3611.7	43.3	41.5
7	1	132.3	12.7	117.4	12050.0	1.3	8110.8	105.4	
20% Fly Ash	2	132.8	12.1	118.4	12897.5	1.4	7322.9	102.5	108.4
	3	132.7	12.2	118.2	11535.0	1.4	8375.0	117.3	
7	1	134.2	13.9	117.9	11515.0	0.9	8005.6	72.1	
20% Fly Ash Soaked	2	134.4	13.9	118.1	3882.5	1.0	7203.0	72.0	72.0

Table A 5.4

Summary of M_R with Curing Time for
Country Club Road, Payne County, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
<u>Field Mixed Samples at 30% Fly Ash</u>									
Target Conditions-->				132.6	11.9	118.5			
3	1	2	10.1				59006		
		4	10.1	125.6	11.8	112.3	66139	65182	
		6	10.2				70401		
									85880
3	2	2	9.7				100830		
		4	9.7	127.6	10.1	115.9	105437	106579	
		6	9.6				113469		
7	1	2	9.2				142623		
		4	9.1	123.1	12.8	109.1	147002	145521	
		6	9.1				146939		
									141765
7	2	2	9.2				132835		
		4	9.1	128.6	12.8	114.0	140174	138008	
		6	8.9				141016		
14	1	2	9.2				186539		
		4	9.1	131.8	11.7	118.0	183495	181018	
		6	9.2				173019		
									164908
14	2	2	9.5				150909		
		4	9.2	125.0	12.7	110.9	145426	148798	
		6	9.2				150060		

Table A 5.4 (con't)

Summary of M_R with Curing Time for
Country Club Road, Payne County, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
<u>Field Mixed Samples at 30% Fly Ash</u>									
Target Conditions-->				132.6	11.9	118.5			
28	1	2	12.2				140015		
		4	12.1	126.3	10.6	114.2	147103	144929	144929
		6	12.0				147668		
56	1	2	11.5				119833		
		4	11.3	120.7	12.5	107.3	132525	131479	
		6	11.1				142078		
									146798
56	2	2	11.6				153111		
		4	11.5	124.1	11.9	110.9	165653	162117	
		6	11.2				167587		

Table A 5.5

Summary of M_R with Curing Time for
Country Club Road, Payne County, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples at 16% Fly Ash									
Target Conditions-->				132.6	11.9	118.5			
1	1	2	12.3	131.7	12.5	117.1	141215		
		4	12.3				143491	142549	
		6	12.1				142940		
									134194
		2	12.1				122079		
1	2	4	12.1	130.4	12.3	116.1	127197	125838	
		6	12.0				128137		
		2	11.3				37771		
3	1	4	11.3	130.2	12.8	115.4	38776	38574	
		6	11.3				39176		
									38025
		2	11.3				36185		
3	2	4	11.3	126.4	12.8	112.1	37657	37476	
		6	11.3				38587		
		2	11.7				45559		
7	1	4	11.7	131.8	13.1	116.5	44368	45078	
		6	11.6				45306		
									44531
		2	11.7				42960		
7	2	4	11.6	130.4	13.1	115.3	43829	43984	
		6	11.5				45163		

Table A 5.5 (con't)

Summary of MR with Curing Time for
Country Club Road, Payne County, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	MR, psi	Average MR Spec.	Average MR Curing Time
Laboratory Mixed Samples at 16% Fly Ash									
Target Conditions-->				132.6	11.9	118.5			
		2	11.7				52983		
14	1	4	11.6	130.6	14.2	114.4	54937	55407	
		6	11.6				58300		
									55407
		2	11.7				93187		
14	2	4	--	130.4	12.5	115.9	--	96910	
		6	11.6				100633		
28	1	2	11.5				63888		
		4	11.4	131.8	13.2	116.4	64204	64193	64193
		6	11.3				64488		
55	1	2	11.9				79703		
		4	11.8	125.2	12.7	111.1	85421	83490	
		6	11.8				85347		
									73621
55	2	2	11.8				63359		
		4	11.8	130.8	13.9	114.8	63493	63751	
		6	11.8				64402		

Table A 5.6

Summary of M_R with Percent Additive for
Country Club Road, Payne County, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples Cured 7 Days									
7	1	2	9.2				6127		
0%		4	9.4	132.4	14.5	115.6	6911	6870	
		6	9.5				7573		
									6314
7	2	2	9.1				5399		
0%		4	9.2	133.2	14.9	115.9	5783	5757	
		6	9.2				6090		
7	1	2	12.5				193766		
8%		4	12.4	131.1	12.5	116.5	195846	195084	
		6	12.4				195640		
									196980
7	2	2	12.4				206071		
8%		4	12.4	131.0	13.0	115.9	201506	198876	
		6	12.4				189052		
7	1	2	12.5				218085		
12%		4	12.3	129.6	11.8	115.9	218940	217585	
		6	12.3				215729		
									182325
7	2	2	--				--		
12%		4	12.2	129.7	11.8	116.0	146511	147065	
		6	12.1				147618		

Table A 5.6 (con't)

Summary of M_R with Percent Additive for
Country Club Road, Payne County, Ok

Curing Time, days	Spec. No.	Confining Stress, psi	Dev. Stress, psi	Moist Density, pcf	w, %	Dry Density, pcf	M_R, psi	Average M_R Spec.	Average M_R Curing Time
Laboratory Mixed Samples Cured 7 Days									
7	1	2	11.7				45559		
16%		4	11.7	131.8	13.1	116.5	44368	45078	
		6	11.6				45306		
									44531
7	2	2	11.7				42960		
16%		4	11.6	130.4	13.1	115.3	43829	43984	
		6	11.5				45163		
7	1	2	12.1				445055		
20%		4	12.1	130.3	12.5	115.8	450959	457104	
		6	12.1				475299		
									412503
7	2	2	12.5				335908		
20%		4	12.4	130.0	12.2	115.9	392923	367902	
		6	12.1				374876		

Table A 5.7

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Country Club Road, Payne County, Ok

		Nuclear w-γ Gauge			Stiffness Gauge		
Date	Test Point	γ_{moist} pcf	w %	γ_{dry} pcf	K MN/m	υ	E MN/m^2
08/06/2007							
Untreated Subgrade	1	125.4	13.9	110.1	14.71	0.25	136.04
		125.3	14.0	109.9	15.13	0.25	139.93
		125.1	14.5	109.2	15.29	0.25	141.41
	Point Average	125.3	14.2	109.7	15.04	--	139.13
	2	127.8	12.8	113.3	15.16	0.25	140.20
		128.2	11.9	114.5	15.23	0.25	140.85
		128.0	12.5	113.8	15.31	0.25	140.59
	Point Average	128.0	12.4	113.9	15.23	--	140.88
	3	128.4	15.1	111.6	15.04	0.25	139.09
		128.7	15.0	111.9	15.80	0.25	146.12
		129.0	15.1	112.1	16.30	0.25	150.75
	Point Average	128.7	15.1	111.9	15.71	--	145.32
	Site Average	127.3	13.9	111.8	15.33	--	141.78

Table A 5.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Country Club Road, Payne County, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	υ	E MN/m^2
11/08/2007							
1 - Day Cure	1	131.7	8.3	121.6	13.11	0.25	121.25
		131.9	8.5	121.7	12.99	0.25	120.14
		132.0	8.0	122.1	12.84	0.25	118.75
	Point Average	131.9	8.3	121.8	12.98	--	120.05
	2	125.6	8.6	115.7	8.10	0.25	74.91
		125.9	8.8	115.7	8.62	0.25	79.72
		126.1	8.5	116.1	8.48	0.25	78.73
	Point Average	125.9	8.6	115.8	8.40	--	77.69
	3	129.6	9.0	118.8	10.84	0.25	100.25
		129.8	9.3	118.7	10.53	0.25	97.38
		130.5	8.8	120.0	11.48	0.25	106.17
	Point Average	130.0	9.0	119.2	10.95	--	101.27
	Site Average	129.3	8.6	118.9	10.78	--	99.67

Table A 5.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Country Club Road, Payne County, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	υ	E MN/m^2
11/11/2007							
4 - Day Cure	1	139.2	8.4	128.4	9.99	0.25	92.39
		139.0	8.4	128.3	12.10	0.25	111.90
		139.2	82.0	128.7	12.07	0.25	111.63
	Point Average	139.1	8.3	128.5	11.39	--	105.31
	2	142.1	7.6	132.1	10.24	0.25	94.70
		141.6	7.9	131.2	10.71	0.25	99.05
		142.1	7.9	131.7	11.56	0.25	106.91
	Point Average	141.9	7.8	131.7	10.84	--	100.22
	3	146.3	8.1	135.4	9.96	0.25	92.11
		146.5	8.0	135.6	11.29	0.25	104.41
		146.2	7.8	135.6	11.37	0.25	105.15
	Point Average	146.3	8.0	135.5	10.87	--	100.56
	Site Average	142.1	8.0	131.9	11.03	--	102.03

Table A 5.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Country Club Road, Payne County, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	υ	E MN/m^2
11/14/2007							
7 - Day Cure	1	124.8	8.3	115.2	18.03	0.25	166.75
		125.2	7.9	116.0	18.62	0.25	172.20
		125.1	8.4	115.4	17.19	0.25	158.98
	Point Average	125.0	8.2	115.5	17.95	--	166.14
	2	131.6	7.9	121.9	5.71	0.25	52.81
		131.0	8.7	120.6	5.68	0.25	52.53
		131.5	8.3	121.4	5.64	0.25	52.16
	Point Average	131.4	8.3	121.3	5.67	--	52.50
	3	125.2	7.0	117.0	7.05	0.25	62.20
		125.9	7.3	117.3	7.11	0.25	65.75
		125.9	7.2	117.4	7.17	0.25	66.31
	Point Average	125.7	7.2	117.2	7.11	--	64.76
	Site Average	127.4	7.9	118.0	10.25	--	94.47

Table A 5.7 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Country Club Road, Payne County, Ok

Date	Test Point	Nuclear w-γ Gauge γ_{moist} pcf	w %	γ_{dry} pcf	Stiffness Gauge K MN/m	υ	E MN/m^2
11/19/2007							
12 - Day Cure	1	124.5	9.0	114.2	20.73	0.25	191.72
		124.6	9.3	114.0	20.54	0.25	189.96
		124.6	9.2	114.1	22.78	0.25	210.67
	Point Average	124.6	9.2	114.1	21.35	--	197.45
	2	125.8	6.2	118.5	17.13	0.25	158.42
		125.6	6.2	118.2	17.18	0.25	158.89
		125.9	6.8	118.0	17.09	0.25	158.05
	Point Average	125.8	6.4	118.2	17.13	--	158.45
	3	127.3	6.1	119.9	9.02	0.25	83.42
		127.5	5.9	120.3	8.82	0.25	81.57
		127.0	5.5	120.3	8.99	0.25	83.14
	Point Average	127.3	5.8	120.2	8.94	--	82.71
	Site Average	125.9	7.1	117.5	15.81	--	146.20

Table A 5.8

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Country Club Road, Payne County, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
08/06/2007									
Untreated Subgrade	1	68.0	--	--	--	--	--	--	--
		69.4	13.2	16.2	24300	86.60	104.62	167.51	4.00
		69.9	(Upper 0.15m)	--	--	--	--	--	--
	Point Average	69.1							
	2	51.1	--	--	--	--	--	--	--
		54.3	18.1	11.4	17070	67.54	83.45	117.67	3.07
		45.8	(Upper 0.15m)	--	--	--	--	--	--
	Point Average	50.4							
	3	19.9	--	--	--	--	--	--	--
		17.7	20.0	10.2	15270	62.69	77.71	105.26	2.87
		16.9	(Upper 0.15m)	--	--	--	--	--	--
	Point Average	18.2							
	Site Average	45.9	17.1	12.6	18880	74.61	88.59	130.15	3.32

Table A 5.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Country Club Road, Payne County, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
11/08/2007									
1 - Day Cure		52.4	--	--	--	--	--	--	--
	1	46.6	5.9	40.1	60165	174.14	186.89	414.74	18.46
		57.5	(Upper 0.1m)	--	--	--	--	--	--
	Point Average	52.2							
		32.9	--	--	--	--	--	--	--
	2	26.5	8.3	27.2	40740	127.71	145.62	280.83	12.32
		24.0	(Upper 0.1m)	--	--	--	--	--	--
	Point Average	27.8							
		50.9	--	--	--	--	--	--	--
	3	54.1	10.0	22.1	33195	109.10	127.73	228.82	11.96
		53.3	(Upper 0.1m)	--	--	--	--	--	--
	Point Average	52.8							
	Site Average	44.3	8.1	29.8	44700	136.98	153.41	308.13	14.25

Table A 5.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Country Club Road, Payne County, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
11/11/2007									
4 - Day Cure		65.6	--	--	--	--	--	--	--
	1	65.2	8.1	28.1	42150	131.16	148.83	290.55	14.52
		66.8	(Upper 0.1m)	--	--	--	--	--	--
	Point Average	65.9							
		61.3	--	--	--	--	--	--	--
	2	71.7	9.9	22.4	33540	109.95	128.58	231.20	14.15
		74.5	(Upper 0.1m)	--	--	--	--	--	--
	Point Average	69.2							
		64.8	--	--	--	--	--	--	--
	3	66.0	6.8	34.0	51045	152.59	168.23	351.87	16.66
		65.4	(Upper 0.1m)	--	--	--	--	--	--
	Point Average	65.4							
	Site Average	66.8	8.3	28.2	42245	131.23	148.55	291.21	15.11

Table A 5.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Country Club Road, Payne County, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
11/14/2007									
7 - Day Cure		62.2	--	--	--	--	--	--	--
	1	65.0	6.3	37.2	55785	163.85	178.07	384.54	15.39
		60.6	(Upper 0.1m)	--	--	--	--	--	--
	Point Average	62.6							
		53.2	--	--	--	--	--	--	--
	2	55.7	8.6	26.3	39405	124.47	142.55	271.63	17.75
		56.8	(Upper 0.1m)	--	--	--	--	--	--
	Point Average	55.2							
		65.0	--	--	--	--	--	--	--
	3	70.5	7.8	29.3	43905	135.44	152.76	302.65	17.19
		69.2	(Upper 0.1m)	--	--	--	--	--	--
	Point Average	68.2							
	Site Average	62.0	7.6	30.9	46365	141.25	157.79	319.61	16.78

Table A 5.8 (con't)

ODOT Chemically Stabilized Subgrade Soil Research

Field Data Summary

Project Location:
Country Club Road, Payne County, Ok

Date	Test Point	Portable FWD E_{vd} MN/m^2	Dynamic Cone Penetration Test (DCP) DCI mm/blow	CBR %	M_r psi	M_r MN/m^2	M_r MPa	E MPa	PANDA Penetrometer Tip Res. MN/m^2
11/19/2007									
12 - Day Cure	1	67.8	--	--	--	--	--	--	--
		74.0	6.2	37.9	56910	166.48	180.36	392.36	19.14
		66.2	(Upper 0.1m)	--	--	--	--	--	--
	Point Average	69.3							
	2	53.7	--	--	--	--	--	--	--
		52.4	6.7	34.8	52245	155.45	170.75	360.14	20.64
		55.4	(Upper 0.1m)	--	--	--	--	--	--
	Point Average	53.8							
	3	61.3	--	--	--	--	--	--	--
		62.7	4.9	49.2	73800	205.72	213.00	508.73	24.28
		62.8	(Upper 0.1m)	--	--	--	--	--	--
	Point Average	62.3							
	Site Average	61.8	5.9	40.6	60985	175.88	188.04	420.39	21.35